CLIMATOLOGY

General and Regional

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CLIMATOLOGY

General and Regional

by

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Preface

This book contains a short and simple restatement of the principles of climatology and a concise summary of the main features of the major climatic regions of the world. It is intended as an introduction to the study of climate for those who will go on to more detailed studies, and as a survey course for those whose primary interests are elsewhere. The treatment is brief and of an introductory character throughout. Some previous knowledge of meteorology will be found helpful, but is by no means essential.

Part I deals with the general principles of climatology. In it are discussed the nature and elements of climate and the factors that give rise to climatic differences and that determine the distribution of climatic types. Attention is also given to the influences exerted by climate on soils and land forms, on plants, and on man and his activities. A simplified classification of climate is developed, making use of fourteen major types of climate and six subtypes. The basis of division into types is primarily that of temperature differences, and secondarily that of precipitation differences.

In Part II the continents are taken up separately, and the characteristics of the major types of climate as they are found on the several continents are stated briefly. The practical purpose of acquainting the reader with the conditions of life and with agricultural pursuits in the various parts of the world is maintained.

The statistical data that are the necessary basis for any discussion of climate are derived originally chiefly from official sources, but are here, in many cases, taken from various compilations and books, most of which are included in the bibliography. My thanks are due to Dean Nels A. Bengtson for his help in many ways, including a critical reading of the manuscript; to the Chief of the United States Weather Bureau for permission to publish this book; and to the technical staff of the Weather Bureau for criticisms and suggestions. Acknowledgment is made also to Mr. George E. Fowler for his care and skill in preparing the drawings, and to my wife for help and encouragement.

T. A. Blair.

Contents

List of Illustrations

PART I

General Climatology

CHAPTER I

Weather and Climate

The air in which we live and move and have our being, as one of the fundamental elements of our environment, is, in its major constituents in all parts of the earth, of practically the same composition, but its influences on plant, animal, and human life vary widely from place to place. These dissimilar effects are mainly the result of differences in the temperature of the air and in the amount of water vapor that the air contains.

Partly because of such changes in the temperature and the water content of the air, and because of the closely related changes in the soil, there is a great variety of plant forms, ranging from palms and bananas which require constant high temperatures, to mosses and lichens which survive where temperatures are below freezing for all but a short period of each year. Similarly, there are many animal species, from camels to polar bears, which are adapted to certain conditions of temperature and moisture. Finally, partly because of the influence of atmospheric dissimilarities, man himself has developed divergent racial types, social habits, and ways of living. These facts not only indicate the significance of atmospheric conditions, but they also call attention to the importance of examining the nature, extent, and distribution of atmospheric differences as they exist on the earth, and of exploring the multifarious effects of such diversity.

This elemental necessity of life, the atmosphere, whose modifications are of universal concern, is a simple mixture of colorless and odorless gases. Water in its gaseous form, called *water vapor* or *humidity,* is an essential part of the atmosphere, but it is present in quite variable quantities, ranging from almost none in dry cold air to about 4% of the total volume of warm and moist air. The other gases that make up the air remain permanently in gaseous form and remain mixed in almost constant proportions in the lower air at all times and in all parts of the world. Nitrogen and oxygen

constitute about 99% of the volume of air, excluding the water vapor. Several other gases make up the remaining 1%; carbon dioxide (CO_2) and ozone are the most important of these gases in their relation to life. In addition, the air always contains in suspension a great number of solid particles of minute size, known as *dust,* and frequently contains liquid or solid water in the form of fog, clouds, or precipitation.

Weather

The air is subject to varying influences from the sun and the earth, and it moves with great freedom over the earth's surface. For these reasons its distribution and its physical condition are continually changing. The condition and behavior of the air at a given time and place constitute *weather.* In order to describe and record the weather, we need instruments for the accurate measurement of the physical properties of the air. We must measure or observe (1) the temperature of the air, (2) its pressure, (3) the speed and direction of its motion, (4) its moisture content, (5) the state of the sky as to cloudiness or the occurrence of precipitation at the time of the observation, and (6) the amount of precipitation since the last observation. These are the six most important *weather elements.* Meteorology, as the science of the weather, attempts to apply physical principles to an explanation and interpretation of all the varied weather phenomena.

Climate

For many purposes it is more important to know, not what the weather in Ohio or in Chile is today, but what it usually is. In other words, we must know what the *average* condition of the atmosphere is—how hot in summer, how cold in winter, how much rain or snow falls in a year, whether the air is moist or dry, and innumerable other questions of this kind. Thus we are often interested in the *climate* of a place rather than in the weather. The weather of a given moment involves a number of elements, as has been noted, and is difficult to state completely and accurately. Climate, involving the combination and integration of the ceaselessly changing weather conditions, is a much more complex and difficult concept. Climate is the summary or the resultant of all the manifold weather influences. As such, it is one of the most im-

portant and influential factors of our environment, and in many cases it is the one natural element of greatest significance in the life of man.

Climatology

A discussion of the phenomena of climate is the province of the science of climatology. Climatology treats of the component elements of weather and climate, such as temperature and rainfall, of their actual distribution over the earth, and of the factors which determine and control their distribution. Since climate has so many far-reaching, practical, and direct applications to the activities of man, climatology emphasizes human relations and is largely descriptive in character. Meteorology is closely related to physics; climatology is intimately connected with geography. These statements apply more particularly to that phase of the subject known as *descriptive climatology.* There is another aspect, called *physical climatology,* which is concerned with the physical processes that produce climate. Physical climatology attempts to analyze and interpret the observational data in terms of cause and effect, and is akin to physics and meteorology.

Climatic data

The basic statistical facts of climate are derived for the most part from *climatic data*—that is, from compilations of long-continued weather records. These compilations constitute the chief source of exact climatic information, and it is therefore impossible completely to separate climatology and meteorology. Weather records are not, however, the only source of climatic information; records of the distribution of plants and animals, and of the seasonal progress of plants, for example, tell much about climate. So, also, does the character of the soil.

Weather records are summarized in various ways to express climatic characteristics. The *average* value of a series of recorded values is universally used in this connection. The word *mean* is used interchangeably with average in most cases, and the word *normal* is often used in the same sense, meaning no more than the average of a long record. The use of *normal* is not to be considered as indicating the existence of an intrinsic, absolutely fixed mean value of a climatic element; no such fixed value is known. No definite rule can be given relative to the number of years re-

quired to establish a satisfactory average. In many parts of the world some or all of the weather elements are extremely variable; in other places there is little difference from year to year. In the latter case, a short record, say of ten years, suffices to give fairly reliable averages, whereas in the former case thirty to forty years may be required for a reasonably stable mean value.

Weather records, as we know them today, are all short in terms of human history. Temperature records could not be obtained until the invention of the thermometer, about 350 years ago. Instruments for measuring atmospheric pressure, wind velocity, and humidity are all of later origin. The standardization of instruments and of observational methods, and the development of systematic, continuous, and comparable records were slow processes. Most of the standardization and organization have been done by governmental agencies since 1860. Hence few accurate weather records are 100 years old. It is unfortunately true, too, that different countries still use different methods of obtaining, tabulating, and summarizing weather observations and climatic data. There are variations in the styles of instruments used and in the definition of terms. Since 1879 a gradual approach toward uniformity has been made under the leadership of an unofficial commission known as the *International Meteorological Organization,* but much remains to be done in this regard. Hence the data from different countries are not always strictly comparable. Those for pressure, temperature, and rainfall are fairly so. In the following pages, when instruments are described or details of procedure discussed, the reference is to the practice in the United States as standardized by the United States Weather Bureau.

The lengths of records actually used in determining averages differ greatly. Over much the greater part of the earth's surface, records made under standard conditions are widely scattered, of short duration, and incomplete as to some of the important elements of the weather. It becomes necessary, therefore, to use that which is to be had rather than that which is to be desired. The definition of *climate* as the summation of weather conditions at a given place over a long period is incomplete and inadequate; something further must be said about the length of the period in mind, but this will be postponed until we have examined the nature and variations of the climatic elements.

CHAPTER II

Temperature as a Climatic Element

The temperature of the earth's surface and of the air near the earth is obviously a factor of great importance in the productiveness of the soil and in the distribution of plant and animal life. The temperature of land and water surfaces is closely related to the temperature of the overlying air; there is a mutual interchange of heat between them, but in discussing weather and climate, *temperature means the temperature of the air.*

Radiation

What one feels as heat when one stands before an open fire has traveled from the fire to the body in a form known as *radiant energy,* or *radiation.* The light from the sun or from an electric lamp is of this same nature; so are X-rays and the waves used in radio broadcasting. A land surface cools at night by sending out waves of radiant energy. In short, all bodies emit radiation and in the process lose some of their own energy, which is evidenced by a loss of heat. Radiation travels in the form of waves with the speed of light, and travels best in empty space; it can, however, penetrate all kinds of matter to a greater or lesser extent. The various forms of radiation are essentially the same, differing only in length of the waves.[1] Three things may happen to radiation when it comes into contact with matter in solid, liquid, or gaseous forms. The waves may pass through the substance without being affected, and are then said to be *transmitted.* They may be *reflected*—turned back unchanged except in direction. Third, they may be *absorbed,* in which case they cease to be radiant energy and are transformed into other forms of energy, frequently heat. Radiation is not heat until it is absorbed.

Insolation

The intensity of radiation—that is, the rate of emission of radiant energy—increases very rapidly as the temperature of the emitting body increases. Since the sun has a temperature of approximately 10,000° F., there is an enormous stream of energy

[1] **H. A. Perkins,** ***College Physics*** **(Prentice-Hall, Inc., 1938), pp. 257–270.**

radiating from it in all directions. The earth intercepts only an extremely small part of the solar output, but this small portion is the sole important source of the heat of both the atmosphere and the surface of the earth. The heat received from other heavenly bodies and from the interior of the earth is negligible. The radiant energy received from the sun is given the special name of *insolation.*

For the purpose of determining how much heat the earth receives from the sun each minute, many measurements of solar radiation have been made with specially designed instruments called *pyrheliometers.* In order to eliminate from these observations the effects of the atmosphere and of the varying distance of the earth from the sun, calculations are made of the amount of energy received at the outer limit of the atmosphere at the average distance of earth from sun. The radiation thus received per minute on a square centimeter of surface at right angles to the sun's rays is called the *solar constant* of radiation. Briefly, the solar constant is the average intensity of solar radiation at the outer limit of the earth's atmosphere. Observations now indicate that this average value, expressed in heat units, is about 1.94 calories per square centimeter each minute. A *calorie* is the amount of heat necessary to raise the temperature of one cubic centimeter of water from 15° to 16° C. But the sun varies in its activity and in the amount of radiation it emits, and hence the so-called solar constant is not in fact entirely constant. It probably changes from time to time by as much as 3% of its average value.

More important in relation to temperatures at the earth's surface than any variations in the solar constant is the fact that the radiation is not evenly distributed over the world. Different parts receive quite different amounts, and at any given place the amount received varies with the time of year and the condition of the air. The following astronomical and physical factors, in addition to the solar constant, determine the income of solar energy at the earth's surface:

Angle of incidence

The inclination of the sun's rays to the horizontal varies with the latitude, the time of year, and the time of day. Within the tropics the sun is overhead at noon on one or two days each year

and is comparatively high at all seasons. Except within the tropics, the sun is never vertically overhead; its noon elevation decreases with increasing latitude and changes greatly with the seasons. Between the tropics and the poles the noon sun is 47° higher at midsummer than at midwinter. Within the polar circles the sun never rises higher than 47°, and for at least one twenty-four-hour period it is continuously below the horizon. The higher the sun, the greater the amount of heat a given horizontal surface will receive; for, as the rays become more oblique, they are spread out over a larger area. Differences in elevation of the sun, or conversely, in the angle of incidence of the sun's rays, are therefore a very important cause of differences in the heating of the earth's surface.[2]

Duration of sunshine (Length of day)

The revolution of the earth around the sun and its rotation on an axis having a nearly constant direction in space not only result in the changing elevation of the sun just described, but also produce seasonal and latitudinal variations in the daily duration of sunshine. At the equator the time between sunrise and sunset is always twelve hours, and at the time of the equinoxes, March 21 and September 22, days and nights are equal everywhere. But from the time of the winter solstice, December 21, the days grow longer in the Northern Hemisphere and shorter in the Southern Hemisphere until the summer solstice, June 21; after this date they again grow continuously shorter north of the equator and longer south of the equator until December 21.

MAXIMUM LENGTH OF DAY AT DIFFERENT LATITUDES

Latitude	*Longest Day or Night*
0	12 hrs.
17	13 "
31	14 "
41	15 "
49	16 "
58.5	18 "
63.4	20 "
66.5	24 "
67.4	1 mo.
69.8	2 "
78.2	4 "
90.0	6 "

The length of the day in summer and of the night in winter increases steadily from equator to poles, as is shown in the accompanying table for certain latitudes at the time of the solstices. These values do not take into account the bending (refraction) of the sun's rays by the atmosphere. The effect of such refraction is to lengthen the day by a few minutes in lower and middle latitudes

[2] T. A. Blair, *Weather Elements*, Rev. Ed. (Prentice-Hall, Inc., 1942), pp. 91–94.

the nature of the surface and the angle of incidence. In general over land surfaces, a large portion is absorbed and used in heating a thin layer of soil. Water surfaces also absorb a large part of the incident radiation, but this absorbed energy is less effective in raising the temperature of a water surface than of a land surface for the following reasons: (1) the radiation penetrates to greater depths (in clear, quiet water to more than 1,500 feet); (2) a part is used in evaporating the water instead of heating it; (3) waves and currents mix the warmed water with other water, thereby again increasing the mass to be heated; and (4) water requires more heat than land to raise its temperature a given amount (its specific heat is greater).

A good absorber of radiation is always a good radiator of its own energy. The land which heats rapidly under the influence of insolation also cools rapidly by radiation, and the water which warms slowly also cools slowly. For these reasons land areas become hot by day and in summer, and cold by night and in winter, as compared with water surfaces under the same conditions. This contrasting behavior of land and water greatly influences the climates of the world.

The Heating and Cooling of the Air

There are only three methods of transmitting heat: radiation, conduction, and convection. Changes in temperature may also be brought about by the absorption of radiation and by changes in latent heat. These are the physical processes by which the air is heated and cooled. As previously stated, the temperature of the air is not much affected, directly, by sunshine. It is more affected by earth radiation, because the longer waves sent out by the earth are partly absorbed by the air, especially by its water vapor and its cloud particles. The air—especially the upper air—loses some heat also by radiation of its own energy. These processes of absorption and radiation are, however, usually less important in changing the temperature of the lower air than are the two other processes, *conduction* and *convection.*

Conduction

Conduction is the process by which heat is transferred through a substance from molecule to molecule. When one end of an iron

rod is heated, the other end becomes hot by conduction. Conduction is always from the warmer to the colder substance. When cool air comes into contact with a warm surface, the air is warmed by conduction from the earth. If the air is warmer than the soil, it is cooled by conduction of some of its heat to the earth. Conduction through the air is very slow and extends only a few feet into the air in a single day or night, but the irregular, turbulent movements of the air extend these effects to considerable heights. The air near the earth, therefore, tends to assume the temperature of the surface with which it is in contact, but, because the air is always in motion, an absolute equilibrium is never reached.

Convection

If a given mass of air is heated to a higher temperature than the surrounding air, it expands and becomes less dense and, therefore, lighter than the air around it. The colder, denser air then pushes it out of its place and forces it upward. In ordinary language, the warm air rises, as, for example, over a heated radiator, and cooler air descends to replace it. This process of transferring heat by the movement of warm air upward and cool air downward is the process of *convection.* Convective movements are facilitated by sloping surfaces; cool air moves downslope readily, and warm air upslope.

But air, like other gases, also expands when the pressure upon it is reduced. While air is rising it is continually getting above some of the weight of the lower air, and into regions of less pressure. As the pressure upon it decreases, the air expands. In expanding it uses up some of its energy, and is thereby cooled. As a result of this process, rising air tends to cool about 5.3° F. for each 1,000 feet of ascent, unless condensation occurs in it. Similarly, descending air is compressed and warmed at the same rate. This is the *adiabatic rate,* and applies to rising or descending air that is not being affected by other heating or cooling processes. When condensation of water vapor occurs in rising air, the rate of cooling is reduced, because the change from a gas to a liquid or solid "releases heat." Similarly, evaporation in descending air retards the rate of warming.

Five physical processes, therefore, influence the temperature of the air: absorption, radiation, conduction, convection, and changes

in latent heat. Heat is released by the processes of condensation, freezing, and sublimation; it is absorbed by evaporation and thawing. In addition, horizontal movements of air from one region to another greatly affect the temperature at a given time and place by transporting warmer or colder air. As a result of all these influences, the average decrease of temperature with altitude in the free air up to heights of three to ten miles is found by observation to be about 3.2° F. per 1,000 feet. This varies widely from day to day, however. In particular, the air near the ground often becomes colder than that aloft, as during clear, calm nights when the earth and the air near it cool rapidly. This condition is known as an *inversion* of temperature. The actual rate of change of temperature with elevation in the air at any time is called the *lapse rate.*

Temperature Data

Temperature data for climatic purposes are usually obtained by daily readings of registering maximum and minimum thermometers. One reading each twenty-four hours gives the highest and lowest temperatures occurring within that period. *Thermographs* are instruments which trace a continuous record of temperature, and they are frequently used to supplement the records obtained from maximum and minimum thermometers. From the records of these instruments, air temperatures at the end of each hour are often recorded. In obtaining temperature readings it is important to maintain a free movement of air across the thermometers and at the same time to protect the thermometers from direct sunshine and, as much as possible, from reflected heat; otherwise the instruments will not have the same temperature as the air.

Temperature tables, daily values

From daily readings of maximum and minimum thermometers continued at a fixed location for a series of years, much can be learned about the weather and climate of the locality. Some of the important values obtainable are illustrated in the accompanying table. Columns *1* and *2* give the highest and lowest temperatures occurring each day, midnight to midnight, during March, 1937, at Omaha. In column *3* are the *mean temperatures,* obtained by taking the average of the maximum and minimum for

each day. The daily mean may also be obtained by using the mean of the twenty-four hourly values shown by a thermograph trace, but it has been found by experience that the much simpler method used in the table gives a sufficiently accurate value for climatic purposes.

TEMPERATURE RECORD, °F., AT OMAHA, NEBRASKA, FOR MARCH, 1937

Date: March	*Max.* 1	*Min.* 2	*Mean* 3	*Range* 4	*Varia-bility* 5	*Normal* 6	*Dept. from Normal* 7
1	52	21	36	31	10	30	+ 6
2	51	29	40	22	4	31	+ 9
3	52	35	44	17	4	31	+13
4	44	30	37	14	7	31	+ 6
5	69	31	50	38	13	32	+18
6	74	37	56	37	6	32	+24
7	58	30	44	28	12	33	+11
8	40	25	32	15	12	33	− 1
9	33	20	26	13	6	34	− 8
10	43	24	34	19	8	34	0
11	41	24	32	17	2	35	− 3
12	38	27	32	11	0	35	− 3
13	32	24	28	8	4	36	− 8
14	30	23	26	7	2	36	−10
15	39	19	29	20	3	36	− 7
16	37	23	30	14	1	37	− 7
17	46	33	40	13	10	37	+ 3
18	61	27	44	34	4	38	+ 6
19	46	32	39	14	5	38	+ 1
20	42	26	34	16	5	39	− 5
21	46	27	36	19	2	39	− 3
22	49	36	42	13	6	40	+ 2
23	52	41	46	11	4	40	+ 6
24	49	22	36	27	10	41	− 5
25	26	14	20	12	16	41	−21
26	22	19	20	3	0	42	−22
27	29	12	20	17	0	42	−22
28	32	29	30	3	10	43	−13
29	38	29	34	9	4	43	− 9
30	46	27	36	19	2	44	− 8
31	56	30	43	26	7	44	− 1
Mean	44.3	26.6	35.4	17.7	5.8	....	− 1.6
Normal	46.5	27.5	37.0	19.0	....	37.0	......

An important feature of climate as related to temperature is shown in column *4*. The *daily range* is the difference between the

highest and lowest temperatures of the day. Note, for example, that the mean temperature on March 3 was 44°; the range was 17°, from a maximum of 52° to a minimum of 35°. The mean temperature of the 18 was also 44°, but the range was just twice as great; the maximum was 9° higher and the minimum 8° lower than on March 3. The days were actually quite different, although their mean temperatures were the same. Climates in different parts of the world show considerable differences in the normal daily range of temperature—that is, in the amount of warming by day and of cooling by night.

The next column gives information concerning the variability of the weather. The *daily variability* is the difference between the mean temperature of a given day and of the preceding day, without regard to the sign of the change. For example, the mean on March 23 was 46°, and the change from the previous day was 4°; on March 24 the mean dropped to 36°, giving a change of 10°. During this month the greatest change from one day to the next was 16°, and the least was zero. At the foot of the column it is seen that the *mean variability* for the month was 5.8°.

The *normal mean temperature* for each day of March is entered in column *6*. These values are derived from a forty-two years' record of the daily temperatures of March, and have undergone some smoothing to remove what appear to be accidental irregularities. Note that the advent of spring, the gradual coming of warmer weather, is shown by the steady rise in the daily normals from 30° on March 1 to 44° on the 31, an increase of nearly one-half degree per day. The actual temperatures for this particular March show no such regularity; the warmest day was March 6, and the coldest days come near the end of the month. The unsystematic nature of the seasonal advance is shown also in the last column, listing the departures from normal—that is, the differences between corresponding entries in columns *3* and *6*. The sign is + when the day was warmer than normal and — when it was colder than normal. Notice how the signs vary, several consecutive days of warm weather alternating with short periods of below-normal temperature. This is the usual way in which the daily temperatures vary in middle latitudes, but sometimes there are more frequent changes of sign than in this example, and sometimes warm or cold spells persist for longer periods.

At the foot of these several columns we see that the *mean daily maximum* was 44.3°, and the *mean daily minimum* was 26.6°. By averaging these we get the *mean temperature* of the month, 35.4°, and by subtracting them we get the *mean daily range,* 17.7°. From the data given in the bottom line, these values may be compared with the corresponding normal values for March. The *absolute monthly range* is the difference between the highest and lowest temperatures of the month; in this case it is 74—12, or 62°.

Temperature tables, monthly values

After detailed daily records, such as those given for Omaha, have been maintained continuously over a long period, the monthly averages and extremes, as set out in the following table for Chicago, become climatic data of great value. Columns *1, 2,* and *3* give for each month and for the year the normal values of mean daily maximum, mean daily minimum, and mean temperature. From columns *1* and *2* the mean daily range may be calculated; thus, for the year, the normal daily range is 14.8° (56.7—41.9). From column *3* we find that July is the warmest month on the average and January the coldest. The *annual range* is defined as the difference between the mean temperature of the warmest month and of the coldest month. We see that the mean annual range at Chicago is 48.5° (72.9—24.4).

The highest and lowest monthly means that have occurred in the sixty-six years of record are given in columns *4* and *5*. From these columns we learn, for example, that the coldest January was 29° colder than the warmest January, but that the warmest and coolest Augusts differed by only 11.4°, and in general that the winter months vary more from year to year than do the summer months. In columns *6* and *7* are recorded the *absolute extremes,* the highest and lowest temperatures that have been observed in sixty-six years, occurring perhaps on only one day of that period. From these entries we find that the *absolute range* of temperature has been 128°, from an absolute maximum of 105° in July to an absolute minimum of —23° in December. The next three columns tell us how many days of hot weather with maxima above 90°, and how many days with freezing temperatures and with zero temperatures may be expected in Chicago, and during what months they occur. At the bottom of the table the data on first

TEMPERATURE AVERAGES AND EXTREMES, °F., AT CHICAGO, ILLINOIS
FOR THE 66-YEAR PERIOD, 1871–1936

Month	*Mean Daily Max.*	*Mean Daily Min.*	*Mean Temp.*	*Highest Monthly Mean*	*Lowest Monthly Mean*	*Abs. Max.*	*Abs. Min.*	*Av. No. days Max. above 90°*	*Av. No. days Min. below 32°*	*Av. No. days Min. below 0°*	*Av. No. degree days of heating*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Jan.	31.0	11.8	24.4	39.5	10.5	65	−20	0	27	4	1256
Feb.	33.2	19.8	26.5	39.1	14.7	68	−21	0	23	2	1083
Mar.	42.8	29.0	35.9	47.6	27.8	81	−12	0	18	*	903
Apr.	54.6	39.4	47.0	55.5	39.0	90	17	*	4	0	545
May	65.6	49.2	57.4	66.2	50.6	98	27	*	*	0	280
June	75.7	59.3	67.5	76.2	62.0	102	40	2	0	0	69
July	80.6	65.2	72.9	79.4	67.3	105	50	4	0	0	8
Aug.	79.2	64.1	71.6	76.8	65.4	102	47	2	0	0	11
Sept.	73.3	57.4	65.3	71.2	58.0	98	32	1	*	0	94
Oct.	61.7	45.9	53.8	62.0	43.9	87	14	0	1	0	363
Nov.	46.8	33.4	40.1	50.0	32.3	77	−2	0	12	*	742
Dec.	35.2	22.8	29.0	43.5	18.5	68	−23	0	23	2	1112
Year	56.7	41.9	49.3	79.4	10.5	105	−23	10	108	8	6466

Average date of last killing frost in spring, April 16. Latest date, May 25.
Average date of first killing frost in autumn, Oct. 19. Earliest date, Sept. 20.
Average length of growing season, 186 days.

* Less than one.

and last killing frosts and the length of the growing season are derived from the daily records, and have an obvious climatic significance in the consideration of plant growth.

Daily march of temperature

From a long series of hourly temperature readings at a given place, the characteristic temperature changes during the twenty-four hours may be obtained. This cycle of daily changes is called the *daily march* of temperature. Fig. 1 illustrates the general

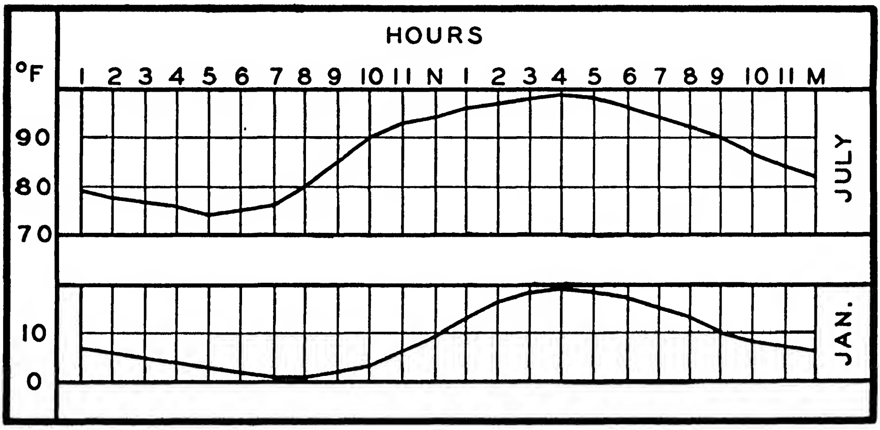

FIG. 1—Typical Daily March of Temperature at Lincoln, Nebraska.

characteristics of the daily march of temperature in continental regions of middle latitudes. The curve results from the interaction of two influences, the incoming solar radiation and the outgoing earth radiation. Shortly after sunrise the gain from insolation exceeds the loss by outward radiation and the temperature begins to rise. The gain continues until mid-afternoon, after which time the outgo is greater than the income, and the temperature begins to decline. The fall continues through the night until the morning sun again becomes effective. This describes the typical daily rise and fall of temperature, but such rhythmic changes do not occur every day. There are occasional interruptions in the smooth daily march of temperature. Changes in wind direction and in cloudiness often cause such irregularities, and may even result in rising temperatures at night and in falling temperatures during the day. In some parts of the world there are more or less regular daily changes of wind direction or of cloudiness,

resulting in mean daily temperature cycles differing considerably from the typical curve shown in Fig. 1.

Annual march of temperature

If we plot mean monthly temperatures for stations in different parts of the world, as in Fig. 2, we obtain a picture of the *annual march* and the annual range of temperature and some illustration of how climates differ in these respects. Note that Winnipeg is warmer than Paris in July, but 40° colder in January. The same is true with reference to Kansas City and Honolulu. There is a peculiar march of temperature at Bombay, with a maximum in May and with a secondary maximum in October. Reasons for such differences will be considered later.

Degree days

A climatic factor of practical importance is the amount of fuel required to maintain a comfortable temperature in homes and offices. A method of expressing this factor numerically has recently been developed under the name of *degree days of heating.* It is assumed that heating is necessary when the daily mean temperature falls below 65°, and that the amount of fuel used in a day is determined approximately by the number of degrees the mean temperature of the day falls below 65°. The additional amount of heat required per degree of fall in outside temperature is not constant, however, but increases as the temperature decreases, because of the increased "leakage" of heat when the difference between outside and inside temperatures is large. The number of degree days of heating is defined as the difference between sixty-five and the mean temperature of a given day that is cooler than 65°. The value is zero for all days with a mean of 65° or higher. The monthly number of degree days is the sum of the daily values. The average monthly values for Chicago are listed in the last column of the table.

The number of degree days of heating is one measure of the severity of the winter and also of the frequency of weather cool enough to require a fire at other seasons of the year. It tells something more about the weather than is told by the monthly means. Note, for instance, that there are occasional days in Chicago in July and August when heating is required. With the develop-

ment of summer cooling and conditioning of air within doors, there is coming into use an analogous expression of the number of degree days of cooling, representing the accumulated excess of the mean daily temperatures *above* 70° (or sometimes 72°). This also

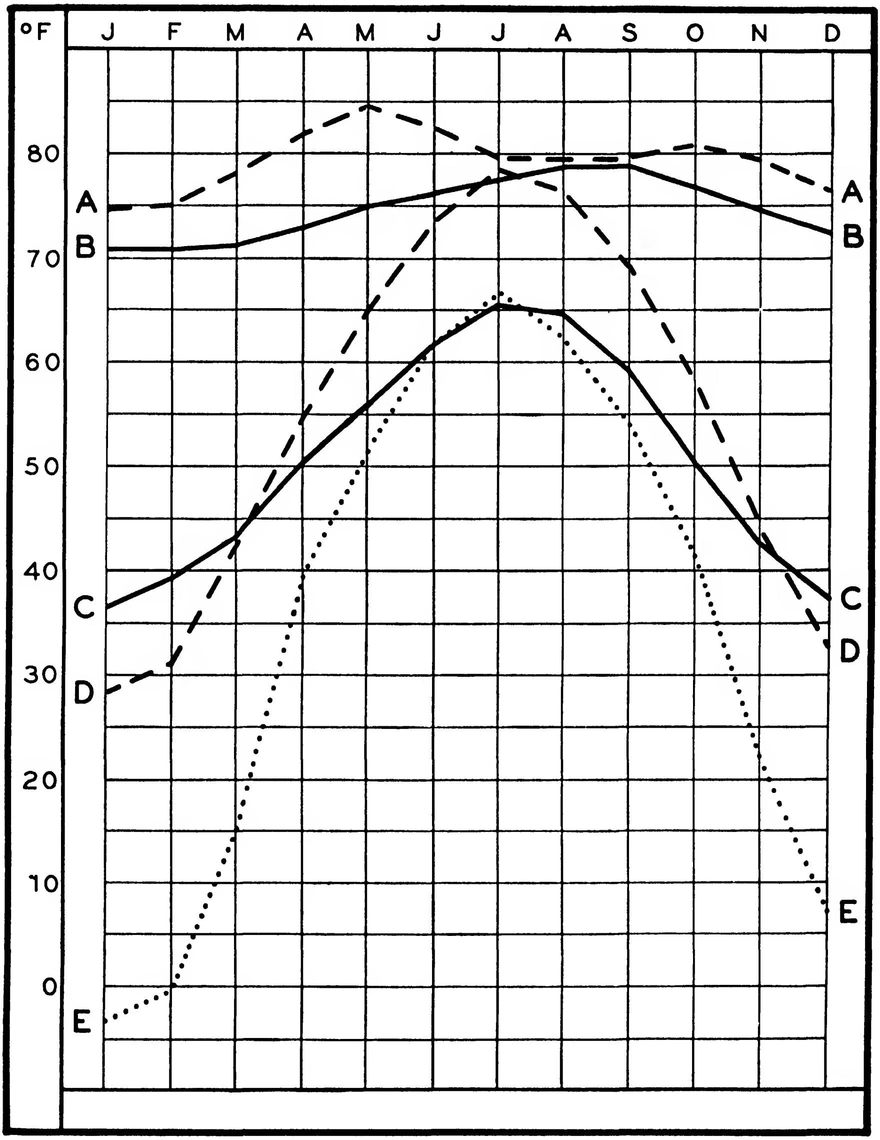

Fig. 2—Some Examples of Annual March and Annual Range of Temperature.
A. Bombay. C. Paris. E. Winnipeg.
B. Honolulu. D. Kansas City.

expresses a fact of practical climatic importance in relation to man. But temperature alone does not determine "comfort"; air movement and humidity are also factors.

These tables and the graph have served to indicate the meaning of the various terms used in summarizing temperature data, and also to illustrate the complexity of the temperature element of climate. Even in describing the climate at a single point of observation, it is impossible to give complete details of the temperature variations (or of the variations of the other elements), and yet it is evident that averages and extremes do not tell the whole story. In practice, a compromise must be made between excessive detail and broad generalization. When the climate of a considerable area or region is being considered as a unit, even greater simplification and omission of detail become necessary.

CHAPTER III

Pressure, Wind, and Moisture as Climatic Elements

Water in its gaseous, liquid, and solid forms is of equal importance with temperature as a component part of climate. Pressure and movement of the air, as such, are generally of lesser significance in determining the characteristics of a climate, but, indirectly, they are of primary importance because of their influence on temperature and moisture.

Pressure and Wind as Climatic Elements

The gases of the air have weight—that is, because of the pull of gravity, they exert a downward pressure. As in the case of liquids, the pressure is transmitted horizontally as well as vertically. Because of the great expansibility of gases, changes in temperature produce large changes in density, and therefore in the weight of a given volume of air. Since the air is very free to move, these changes in density result in movements of the air, and in turn these movements cause a redistribution of the pressure. The approximately horizontal movements of the air are known as *wind.* Temperature, pressure, and wind are thus closely interrelated.

Measurement of pressure

A *mercury barometer* is the instrument used in weather observations for the accurate measurement of the air pressure. This instrument indicates pressure in terms of the length of the column of mercury that the pressure supports. The units of length used are inches or millimeters. A unit of force called the *millibar* is now in general use. A millibar is a force of 1,000 dynes per square centimeter; 1,000 millibars are equivalent to 29.53 inches or 750 millimeters of mercury. A pressure of 29.92 inches, 760 millimeters, or 1,013 millibars is regarded as the normal value of the pressure at sea level at latitude 45°. An *aneroid barometer* measures the pressure of the air directly by the compressive effect

upon an elastic metal box. A *barograph* is an aneroid barometer that makes a continuous record of air pressure.

Pressure gradient

Winds tend to equalize the pressure; their direction and speed are determined in the first instance by the pressure gradient—that is, by the difference in pressure per unit distance. Air tends to move from the higher to the lower pressure at a speed proportional to the pressure difference, but after the motion begins, the direction of movement relative to the earth is modified by the deflecting influence of the earth's rotation, and its speed is modified by friction and turbulence. Moving air always tends to deviate to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

The pressure element

Variations of pressure at the same level seldom amount to as much as 10% of the total pressure, and in themselves have little significance as an element of climate. Neither the changes in pressure at a given locality nor the differences in various parts of the world at low or moderate elevations have appreciable effects on animal or plant life. They are not perceptible to the senses. In mountainous regions or high plateaus, however, the air becomes so thin that it is a physiological factor of some importance. This is mentioned later in connection with other elements of mountain climates. The great importance of pressure in connection with climate is in its relation to the winds and, through them, to temperature, precipitation, and humidity.

The wind element

Wind is in itself a climatic element of considerable importance. Winds affect human comfort and efficiency. By their influence on the rate of evaporation from the skin, they affect the sensible temperature, as has been noted. The light winds and frequent calms of some tropical regions and the concurrent high temperatures are debilitating, and make the heat much less endurable. On the other hand, high winds with temperatures above the body temperature may conduct heat to the body more rapidly than it can be dissipated, and they may thus cause fever and heat stroke.

Low temperatures are more endurable when the wind is light, because increasing the air movement increases the conduction of heat from the body.

Increased wind movement is usually attended by increased evaporation from water and soil surfaces and from vegetation, sometimes resulting in injury to crops. The "hot winds" of the Great Plains cause a wilting and "burning" of the corn fields by overtaxing the moisture-carrying capacity of the plants, as well as by removing moisture from the soil. Winds from different directions and sources bring air of differing characteristics. Storminess, in the sense of frequently changing wind direction and velocity and accompanying changes in other weather elements, is an important element of climate. For these various reasons complete climatic tables must include the prevailing direction and average hourly velocity of the wind by months, the percentage frequency of winds from different directions, and the frequency of calms and of high winds (32 miles or more per hour).

Moisture as a Climatic Element

The amount of water vapor in the air, the prevalence of cloudiness and fogginess, and the number of rainy days are all in themselves features which must be considered in the complete description of a climate, but the greatest significance of water in the air is as the source of precipitation and of soil moisture.

Evaporation

Evaporation is the transformation of a liquid into a gas by the escape of molecules from the free surface of the liquid. Water vapor becomes a permanent, though variable, constituent of the air by the process of evaporation from water surfaces and from soil and plant surfaces. There are three important factors influencing the rapidity of evaporation from a given water surface: (1) the temperature of the water (the higher the temperature, the more rapid the evaporation will be); (2) the dryness of the air into which evaporation is occurring, expressed as relative humidity or vapor pressure deficit (the drier the air, the more rapid the evaporation); and (3) air movement (evaporation increases with wind velocity because the wind removes air that has become moist and replaces it with drier air). In addition, the rate of evapora-

tion from water varies greatly with the size, shape, depth, and salinity of the water bodies, and evaporation from soil and plant surfaces varies with their condition, texture, and exposure.

Measurement of evaporation

The amount of evaporation occurring under natural conditions from soils and plants is obviously a climatic factor of great importance. It is closely related to the water requirements of plants, and to the effectiveness of a given rainfall in promoting plant growth. The actual amounts, however, depend upon so many circumstances and conditions that no such absolute values are available for climatic purposes. It is not even possible to state with much accuracy how much evaporation from a known reservoir or lake will occur under given weather conditions. There are, however, many records of evaporation from small water surfaces, obtained under approximately comparable conditions, and these afford some indication of the relative amounts of evaporation in different parts of the world.

Humidity

The water vapor, like the other gases of the air, exerts a pressure proportional to its density—that is, to the number of molecules present in a given volume. This is the *vapor pressure* of the air, and is one means of expressing the amount of moisture in the air. The amount may also be stated in terms of the weight of water vapor in a given volume of air. This is the usual method of expressing *absolute humidity. Specific humidity* is the weight of water vapor in a unit weight of air.

There is a limit to the amount of water vapor that will exist in a given space at a given temperature. When the vapor pressure reaches a certain value, depending on its temperature, as much water returns to the liquid state (condenses) as that which evaporates. The space or the air is then said to be *saturated.* The possible amount in a given space increases rapidly as the temperature of the vapor increases. Very warm air may have a high absolute humidity and not be saturated, but if this air is cooled sufficiently it arrives at a temperature of saturation. This temperature is the *dew point.* Further cooling results in the accumulation of liquid or frozen water. Thus dew and frost are formed.

The ratio between the actual amount of water vapor present in the air (its absolute humidity) and the possible amount at that temperature is the *relative humidity.* Relative humidity is expressed in percentage, 100% representing complete saturation. Our feeling that the air is dry or moist is largely a response to its relative humidity. Another measure of the difference between the existing moisture condition and a saturated condition is the *vapor pressure deficit* (also called *saturation deficit*), by which is meant the difference between the vapor pressure at saturation and the actual vapor pressure. Vapor pressure deficit is much used by students of plant life as one criterion of the rapidity of loss of water by evaporation and transpiration. The rates of loss of moisture are more nearly related to vapor pressure deficit than to any other one humidity datum.

Measurement of humidity

The process of evaporation uses up molecular energy and therefore has a cooling effect; the cooling is proportional to the rate of evaporation. This fact is used in the measurement of humidity of the air by means of a *psychrometer.* A whirled psychrometer consists of two similar mercury thermometers mounted on the same frame. The bulb of one of them is covered with a thin wick or muslin covering. This bulb is dipped in water and the two thermometers are then whirled in the air. The dry-bulb thermometer indicates the temperature of the air; the wet-bulb, cooled by evaporation, has a lower reading unless the air is saturated. The difference between the two readings is a measure of the humidity of the air, from which the relative humidity, the vapor pressure, and the dew point may be obtained. The term *humidity* as used in climatic tables usually signifies the mean relative humidity. The mean relative humidity of a day is usually obtained by averaging the percentages observed in the early morning and in the late afternoon. Monthly means are averages of the daily means, and annual means are averages of the monthly means.

Effects of evaporation and humidity

The presence of greater or lesser amounts of water vapor in the air affects the temperature of the earth's surface and of the air near the surface. Water vapor absorbs some of the solar radiation

and prevents its reaching the earth. In regions of similar latitude and elevation insolation is therefore not as intense in humid climates as in dry climates, but a large part of short-wave solar radiation does penetrate even humid air. The long-wave radiation emitted by the earth is much more effectively absorbed by water vapor. The rate of cooling by radiation is thus reduced. Hence, water vapor in the air acts as a trap, permitting heat to enter but not to escape. Accordingly, nights tend to be warmer when humidity is high.

The temperature felt by the human body is called the *sensible temperature.* It is not the same as the air temperature, but is affected by the rate of conduction of heat to or from the body by the moving air, and also by the rate of cooling due to evaporation from the skin and from the respiratory passages. Wind and humidity are therefore important factors in determining the sensible temperature. When the skin is moist and exposed to the air, the sensible temperature approximates the wet-bulb temperature. When the air temperature is higher than the body temperature, there is no dissipation of the bodily heat by conduction; evaporation is then the only effective cooling process. Under these conditions moderate air movement increases evaporation, and we are cooled by a fan, but high humidity retards evaporation and is accordingly oppressive and enervating. In cold weather evaporation from the skin is less active, and conduction is the important process by which heat is removed from the body. Wind and high humidity increase the rate of conduction of heat from the body to the air and intensify the feeling of cold. Hence, humid air feels warmer in summer and colder in winter than does dry air.

The total amount of evaporation in a day, month, or year has considerable climatic significance. The effectiveness of precipitation in the production of crops depends in part upon the amount of water lost from plants and soil by evaporation. It takes more water to raise a crop in Arizona than in Minnesota because of the greater evaporation in the hotter, drier climate. Very rapid evaporation caused by high temperature, wind, and low humidity often is responsible for a dessication of crops. The effect of insolation upon the soil is also modified by the amount of evaporation, since evaporation has a cooling effect. Instead of using the total precipitation and the actual temperatures as climatic indices, a

more accurate basis for differentiating climates is obtained by using the ratio of precipitation to evaporation and the ratio of temperature to evaporation.

Cloudiness and sunshine

Clouds are composed of very fine drops of water, particles of snow, or spicules of ice condensed from the water vapor of the air. They result from cooling the air below its dew point. The main process in the formation of clouds is the dynamic cooling by expansion of rising air (adiabatic cooling). The ascent of the air may be caused (1) by convective movements resulting from temperature differences between adjacent portions of air; (2) by forced ascent as wind moves over rising ground; (3) by the meeting of air masses of different densities; or (4) by combinations of these mechanisms. Heavier air forces lighter air to rise. The principal reason for a difference in density of two air masses under the same pressure is a difference in temperature; the warm air is lighter than the cold air. Sometimes a difference in humidity is also important; other conditions being the same, moist air is lighter than dry air.

Thermal convection often occurs over heated land masses in summer. Portions of the lower air become warmer than the surrounding air, and these portions rise. As the air rises, it cools adiabatically. Its dew point also becomes lower as it rises, but, if it cools to the reduced dew point, condensation begins, resulting in the formation of cumulus clouds. At first these are scattered whitish cloud masses with flat bases and irregular rising summits. If rising and condensation continue rapidly, they develop into anvil-shaped cumulonimbus clouds, attended by thunderstorms. When air is forced upward by moving against a mountain slope, condensation generally produces a uniform cloud layer, covering the entire sky, and, if precipitation results, there is steady rain or snow of light to moderate intensity. Similarly, when warm air moves upslope against an opposing mass of colder air, the sky becomes overcast by layer-like clouds, and if rain falls, the rain is of the slow, continuous type. When a stream of cold air moves rapidly against a mass of warmer air, the latter is forced up quickly, and dark, towering clouds develop, followed by heavy rain of short duration, sometimes attended by lightning and thunder.

As a rule, clouds reduce the amount of insolation received at the earth's surface, and hence reduce the warming of the lower air by day, because they reflect a large part of the solar beam and also absorb some of it. In the case of scattered clouds covering only a small part of the sky, the effect of reflection from the clouds is sometimes to increase the total radiation received in a given area. By night, cooling as a result of earth radiation is checked by clouds, because they reflect, or absorb and reradiate, the energy back to the earth. This applies to the lower clouds; high, thin clouds have very little effect on nocturnal cooling. The lower, denser clouds make the days cooler and the nights warmer than they would otherwise be. In high latitudes in winter the night effect is more important than the day effect, and the result of cloudiness is an increase in the mean temperature. In low latitudes cloudiness reduces the mean annual temperature. In weather observations cloudiness is expressed in tenths of the sky covered. In climatic tables the amount of cloudiness is often indicated by tabulating the number of clear, partly cloudy, and cloudy days. A day is considered clear if the average cloudiness is three-tenths or less, partly cloudy if the sky is four- to seven-tenths covered, and cloudy if eight-tenths or more.

The possible amount of sunshine at a given place depends principally upon the latitude and the time of year. The amount actually received in relation to the possible amount is reduced by the cloudiness, fogginess, humidity, and dustiness of the air. Climatically, the amount of sunshine is expressed as the average number of hours of sunshine received per month or per year, and the relative sunniness of a climate is indicated by tabulating the actual hours of sunshine as a percentage of the possible duration of sunshine for the particular location. A certain amount of sunshine is essential for plant growth and for human health. "All the world is cheered by the sun." The rate of growth of plants is largely influenced by the amount of solar energy the plants receive. In high latitudes, because of the long hours of summer sunshine, crops grow rapidly and reach maturity in a short growing season. The duration of daylight as distinct from the intensity of sunshine is of importance in the flowering of many plants; some plants blossom only when the days are comparatively short, others require long days, and a third group is indifferent to the

length of daylight. Sunshine is an important climatic factor also by reason of its effect on the temperature of the soil.

Fog

Fog is condensed moisture in very fine droplets in a layer of air at or near the surface of the earth. Fog is caused by the cooling of a surface layer of air to its dew point. The air is cooled by radiating some of its heat, or by the conduction of its heat to colder surfaces with which it comes in contact, or by both of these processes. Note the contrast between the cooling of a surface layer to produce fog and the cooling by upward movement which is the principal cause of clouds. A fog is called *dense* if it obscures objects at a distance of 1,000 feet or less. Dense fogs interfere with street, highway, and ocean traffic, and especially with air traffic. They cause many shipwrecks and traffic accidents. On the other hand, in some regions of light rainfall, frequent fogs not only reduce the loss of moisture, but they add significant amounts of water for the use of plants. For these reasons, a complete description of a climate requires the tabulation of the average number of dense fogs, their distribution through the year, the number of hours of fog, and the times of occurrence. This is especially important in connection with the location and operation of airports.

Precipitation

Equaling temperature as a climatic element of major significance is rainfall. As in the case of temperature, a simple statement of annual values is not sufficient to characterize the climatic meaning of the precipitation. In order to form a picture of the climate we must know the distribution of rain throughout the year, its variability from year to year, the rate at which it falls, and other details.

Causes of rain

The ascent of moist air, which is the main cause of the formation of clouds, is the sole cause of important amounts of precipitation. It is the only process by which large masses of air are rapidly cooled below their dew point. After the formation of clouds, continued rapid cooling produces precipitation, the rate and amount of fall being related to the rate and amount of cooling and to the absolute humidity of the rising air. A considerable

depth of cloud, containing cloud particles of different sizes, appears to be necessary for copious rainfall. Three different kinds of rain, considered in relation to the causative processes, are frequently recognized: (1) *convectional rain,* resulting from the upward movement of air that is warmer than the surrounding air, the contrast in temperature being associated with the heating of the surface air, the cooling of upper layers of air, or other factors affecting the lapse rate; (2) *orographic rain,* produced when rising ground deflects moisture-laden air upward; and (3) *cyclonic rain,* caused by the meeting of air currents of different temperatures, such as occurs in the cyclonic storms of middle latitudes. This is a much simplified classification. There are various combinations of these processes, and the actual type of rain in any given instance depends much upon the temperature and moisture conditions existing at various levels in the air.

Measurement of rainfall

In the measurement of rain a simple gage often used consists of a cylinder fitted with a receiving funnel eight to ten inches in diameter and exposed on the ground in the open. The depth of rain caught is measured in a tube having one-tenth of the cross-section area of the receiving funnel. Depths are thus magnified ten times, and measurements can easily be made to 0.01 inch. There are *recording* rain gages of several types, and by such means continuous records of the time and amount of rain or snow are obtained. Such records of the intensity of rainfall and of the accumulated amounts in short periods are of considerable climatic and economic significance. The accurate measurement of snow presents some difficulty because of the difficulty of catching a representative amount in a receiver. The depth of snow is obtained by taking the average of several measurements in representative places. The amount of the precipitation from snow—that is, its water equivalent—is obtained by weighing a representative section, or by melting it and measuring the depth of the water.

Tabulating moisture data

The accompanying table for Atlanta illustrates the manner of setting forth some of the important climatic facts about rainfall, cloudiness, humidity, and sunshine at a given location. The first

column shows moderate amounts of precipitation at Atlanta in all months, with the greatest amounts in the coldest months of the year, December to March, and a secondary maximum in July and August. October is the month of least rain and the smallest number of rainy days (see third from last column). A record of the greatest amounts in twenty-four hours (second column) is of importance in planning drainage systems, in indicating the probability of sudden freshets and floods, and in relation to the amount of erosion and the amount of water lost to the soil by rapid run-off.

The record shows that snowfall is of minor importance at Atlanta. In colder regions, where snow accumulates on the ground, it acts as a blanket because it is a poor conductor of heat. A snow cover protects the soil from severe air temperatures, and largely prevents the outflow of heat from the ground. On the other hand, snow does not warm above freezing by day, and it cools rapidly by radiation at night. Hence, a snow cover contributes at the same time to higher soil temperatures and lower air temperatures. The coming of spring is delayed by the presence of snow on the ground and of ice on lakes.

The data for relative humidity show that Atlanta has a rather high humidity throughout the year and no strongly marked seasonal variations. Relative humidity is highest during the cooler parts of the day and lowest when the temperature is high, as is the rule. The greatest amount and the highest percentage of sunshine occur in May and June. The minimum of sunshine and the maximum of cloudiness are in December and January.

Additional information about the rainfall is given by a determination of the average number of rainy days in a month or a year, i. e., days with 0.01 inch or more. In certain parts of the world, there are frequent light, long-continued rains, giving much cloudiness and high humidity, but only a moderate total rainfall. In other areas an equal amount of rain may fall on many fewer days in the form of heavy rain of short duration and at considerable intervals between many sunny days. The climates are quite different in the two cases. Paris has 170 rainy days per year, but a total rainfall of only 22.6 inches; Atlanta has more than twice as much rain—48.6 inches—but rain falls on only 124 days. The average per rainy day is 0.13 inch at Paris, 0.39 inch at Atlanta. This expresses the intensity of the rainfall. The probability of rain is the

AVERAGES AND EXTREMES AT ATLANTA, GEORGIA

PRECIPITATION AND AVERAGE NUMBER OF DAYS ARE FOR THE 59-YEAR PERIOD, 1879–1937.
SUNSHINE AND RELATIVE HUMIDITY AVERAGES ARE FOR PERIODS OF 20 TO 50 YEARS

Month	Precipitation (Inches)				Relative Humidity Per Cent			Sunshine		Average Number of Days					
	Average	Greatest in 24 hrs.	Average Snowfall	Greatest Snowfall in 24 hrs.	6:30 a.m.	Local noon	6:30 p.m.	Total hours	Per cent	Clear	Partly Cloudy	Cloudy	Rain .01 or more	Snow	Dense Fog
Jan.	4.89	4.03	1.0	8.0	80	67	70	152	48	9	8	14	12	2	4
Feb.	4.82	3.63	0.9	6.5	78	64	65	165	53	9	7	12	11	2	3
Mar.	5.35	7.36	0.2	4.0	76	56	60	218	58	12	8	11	11	1	2
Apr.	3.79	4.26	T	1.5	74	54	57	253	65	11	9	10	10	†	1
May	3.50	4.86	0	0	74	53	58	296	69	11	11	9	10	0	†
June	3.75	3.93	0	0	77	53	62	298	69	10	11	9	11	0	†
July	4.60	5.56	0	0	82	57	68	275	61	8	12	11	13	0	†
Aug.	4.21	4.22	0	0	84	59	70	252	59	9	12	10	12	0	1
Sept.	3.15	5.88	0	0	81	56	65	243	65	12	10	8	8	0	1
Oct.	2.74	4.51	0	T	78	55	62	233	66	16	7	8	7	†	1
Nov.	3.95	4.11	T	2.2	77	59	64	190	61	13	7	10	8	†	2
Dec.	4.78	5.72	0.4	6.2	80	67	71	146	47	10	7	14	11	1	3
Year	48.63	7.36	2.5	8.0	78	59	65	2,672	59	130	109	126	124	7	18

T indicates trace of precipitation.
† indicates less than one.

ratio of the number of rainy days to the total number of days in a year. The probability of rain is 0.47 at Paris and 0.34 at Atlanta. The true probability of rain on any given day is related to the weather of the preceding day, since weather conditions tend to persist. The number of days with snow and with dense fog (last two

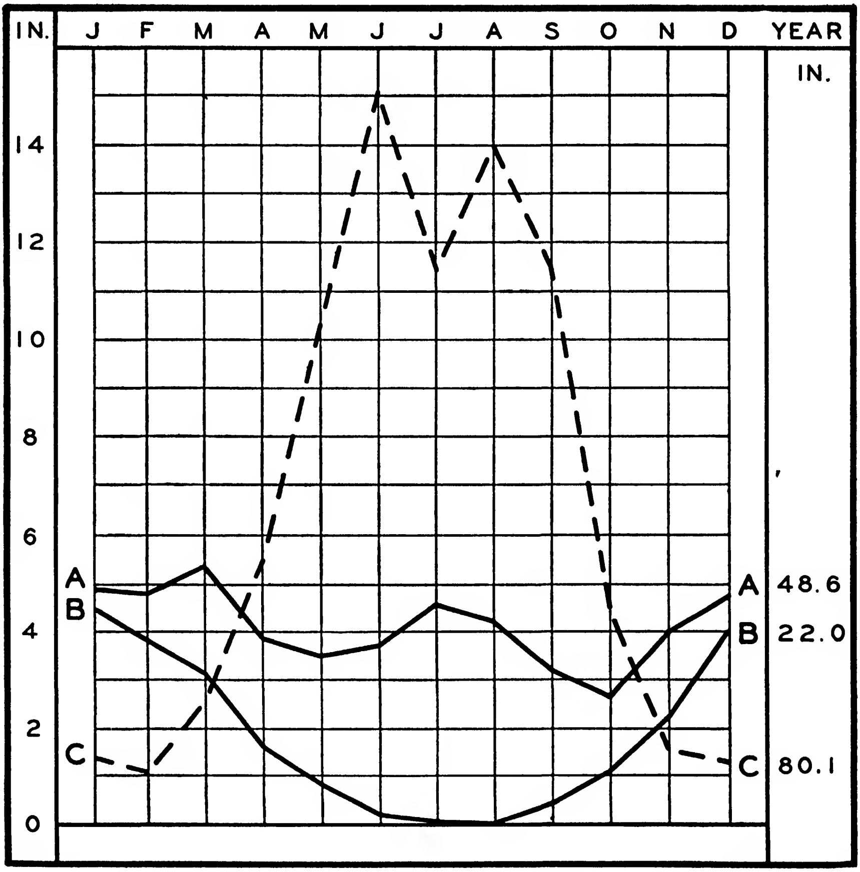

FIG. 3—Monthly Distribution of Rainfall.
A. Atlanta. B. San Francisco. C. Hong Kong.

columns) helps to complete the picture of the climate of Atlanta. Many additional details could be given for an intensive study of the local climate—for example, the duration of the snow cover and the number of days with thunderstorms and with hail.

Seasonal distribution of rainfall. Some other parts of the world have a much more unequal monthly distribution of precipitation than that shown at Atlanta. This is made evident in Fig. 3, where

monthly amounts at Atlanta are compared with those at San Francisco, which has a marked winter maximum and summer minimum, and at Hong Kong, which has heavy rain in summer and light rain in winter. The reasons for these differences will be discussed later. The differences in seasonal distribution are often of considerable significance in the production of crops. In many cases rainfall during the growing season is of more value to plants than an equal amount in the winter, but for other plants the storage of soil moisture during the autumn and winter may be of greater importance. The distribution of precipitation is especially important in regions where the total is likely to be insufficient to produce full yields of the staple crops. In the Great Plains of the United States, for example, the maximum rainfall is in the early part of the growing season, and for that reason these areas are better adapted to the production of small grains than they would be if rain were evenly distributed.

Variability of rainfall. The variability in the amount of rainfall from year to year, either in annual totals or growing-season totals, is a climatic element of importance. Where the precipitation is abundant in some years and markedly deficient in others, there are years of surplus production, and years when production is insufficient for local needs. This makes for uncertainty, disorganizes farm planning, and increases the hazards of farming. In China and India the failure of the expected rains has often led to extensive famines. There is considerable uncertainty of rainfall in most parts of the world, but regions of the greatest percentage variability are often those very regions in which the normal rainfall is barely sufficient. This is to be expected since variations of small amount will make a greater percentage difference the smaller the mean value. This leads to frequent crop failures. In regions of large variability, the monthly, seasonal, and yearly amounts are more likely to be below the mean value than above it. In other words, the most frequent, or most probable rainfall, is somewhat less than the normal (i. e., the average) rainfall. This results from the fact that there are numerous moderately dry months, seasons, and years, and an occasional very wet period. Rainfall reliability is sometimes expressed as *the mean percentage departure from normal.*

The variability in the annual amount of rainfall in the Great

Plains of the United States is illustrated in Fig. 4. Lines connecting points of equal rainfall are called *isohyets.* Note that the isohyet of twenty inches for the average annual rainfall follows the 100th meridian, approximately, from Texas to North Dakota, and that the dotted line, *B*, which is east of the twenty-inch line, represents the western boundary of the area that receives twenty inches or more in half the years. The area between these two curves has an average rainfall of more than twenty inches, but a probable rainfall in any given year of less than twenty inches. The area between the lines *B* and *C* may expect at least twenty inches more than half but less than three-fourths of the time, and the area between *C* and *D* more than 75% of the time but not every year. Note that a large part of Iowa and Wisconsin have had at least one recorded year of rainfall less than twenty inches, although the average is more than thirty inches. The same is true in a narrower strip in other states from Nebraska to Texas, for the line *D* is everywhere east of the line showing a normal rainfall of thirty inches. West of the twenty-inch isohyet is a strip bounded on the west by the line *A* that receives twenty inches in one-fourth of the years, although the average is less than twenty inches.

Droughts. Closely connected with variations in the annual or seasonal amounts of precipitation is the occurrence of droughts. A *drought* is a period of dryness of sufficient length and severity to cause partial or complete crop failure. As crops in different parts of the world are more or less adjusted to normal moisture conditions and normal rainfall distribution for the region, a rainless period that would constitute a drought in one region would not be unusual or injurious in another. It is also true that the severity and effects of long dry periods depend not only on their duration, but also on the attending temperature and wind, on the kind and previous condition of the soil, and on the condition of the crops. *Drought* is therefore a relative term. A tabulation of the frequency of dry periods of various lengths is of value in detailed studies of climate.

Rainfall effectiveness. Further details may be given by tabulating the frequency of days with precipitation of a certain amount, as for instance, 0.1, 0.25, and 1.0 inch.

Whether light or heavy rains are more valuable depends on many conditions. In heavy downpours, most of the rain runs off

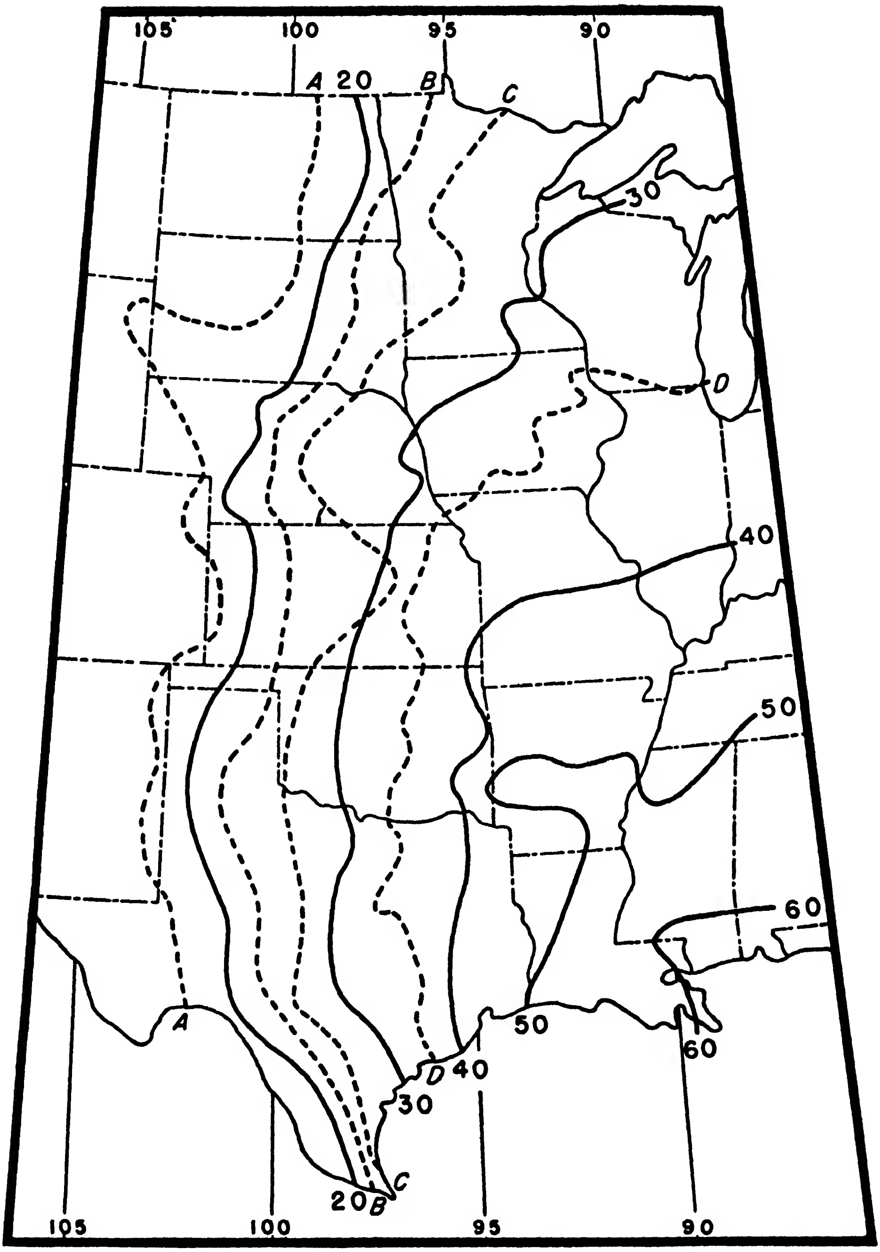

FIG. 4.—Variability of Rainfall in the Great Plains of the United States. Solid lines are isohyets of average annual (normal) rainfall in inches. Dotted lines are percentiles. The entire area east of *A* has 20 inches or more in at least one-fourth of the years; east of *B* in one-half the years; and east of *C* in three-fourths of the years. West of *D* there has been at least one year with less than 20 inches, and the entire area has had at least one year with more than 20 inches. (Percentiles after E. E. Lackey.)

the surface, carrying valuable soil with it, and does not become available to the plant roots. On the other hand, small amounts of rain followed by warm and sunny weather are quickly lost by evaporation and do not penetrate to sufficient depths to be of value. Light rains with cloudiness and high humidity, lasting several days, are effective in adding to the soil moisture, as are also moderate amounts at intervals.

Climatically, the effectiveness of rainfall is governed by the amount that is absorbed by the soil and becomes available to plant roots. In addition to the total rainfall, account must be taken of (1) the character and condition of the soil and of the vegetative cover, (2) the rate of fall and seasonal distribution of the rain, and (3) the losses by evaporation. A "rain factor" sometimes used to express rainfall effectiveness is obtained by dividing the amount of rain (expressed in millimeters) by the mean temperature (expressed in degrees Centigrade). This is for application climatically to large areas and assumes that evaporation is approximately proportional to mean temperature; other factors which are subject to much local variation are disregarded.

Summary

The elements of climate are those various atmospheric conditions which combine and interact to make a given climate what it is. Stated briefly, the important elements are only three—the temperature, moisture, and movement of the air. These are continuously variable, however, and they occur in an infinite variety of combinations. Hence it is impossible to describe a climate completely. The most accurate statement of the character of a climate is obtained by a series of tabulations of numerical values of the climatic elements. Tables of temperature, precipitation, humidity, cloudiness, sunshine, and wind can be elaborated in great detail to give more and more comprehensive information about a given climate. In order to obtain an understanding of climatic differences, it is necessary to compare such tables for different parts of the world not only with each other, but with tables f [illegible] te with which one is familiar by personal experience.

To a certain extent plants summarize the climat [illegible] which they have been subjected, and different plan [illegible] r different climatic conditions. Thus, a knowledge o [illegible] tive

and cultivated plants of a region, together with some knowledge of the climatic requirements of such plants, gives an easily understood characterization of the climate of the region. Coffee and coconuts immediately suggest a tropical climate; spruce forests suggest a cold climate. Observations of the time of leafing, flowering, fruiting, and other stages in the development of plants are known as *phenological observations.* Phenological records for the same species of plants in different localities afford some indication of the climatic differences between the regions.

CHAPTER IV

Climatic Controls

Having examined individually the more important components of climate, and having noted how they are observed and tabulated, we may now investigate the general factors which determine their distribution over the earth. We wish to ascertain what it is that controls the distribution of the climatic elements, and why different parts of the earth have different climates.

The General Distribution of Temperature and Precipitation

Before to number enumerating the controlling influences it will be well to note the main features of the observed distribution of the two most important elements of climate—temperature and precipitation. In Figs. 5, 6, and 7 the mean sea level temperatures of the world are shown for the year, for January, and for July, respectively. It is to be noted that these figures represent, not the actual temperatures, but the temperatures reduced to sea level. The effects of elevation on temperature will ~~are~~ eliminated by assuming a normal decrease of temperature with elevation. A rate of change now often assumed is 2.75° F. per 1,000 feet, or 0.5° C. per 100 meters. One reason for this usage is that the local variations of elevation and exposure in mountain regions result in so many large local variations in temperature that it would be impossible to represent them on a small-scale map. A second reason for reducing to sea level is that the temperature differences due to altitude, if entered, would conceal the influence of other factors. These charts therefore show the effects of the other climatic controls to be discussed in this chapter, but not the effects of elevation. The reasons for the irregularities of the existing temperature distribution will be discussed in connection with the various controlling influences.

The map of mean annual precipitation, Fig. 8, shows the actual **average rainfall** (as far as it is known) over the land areas of the

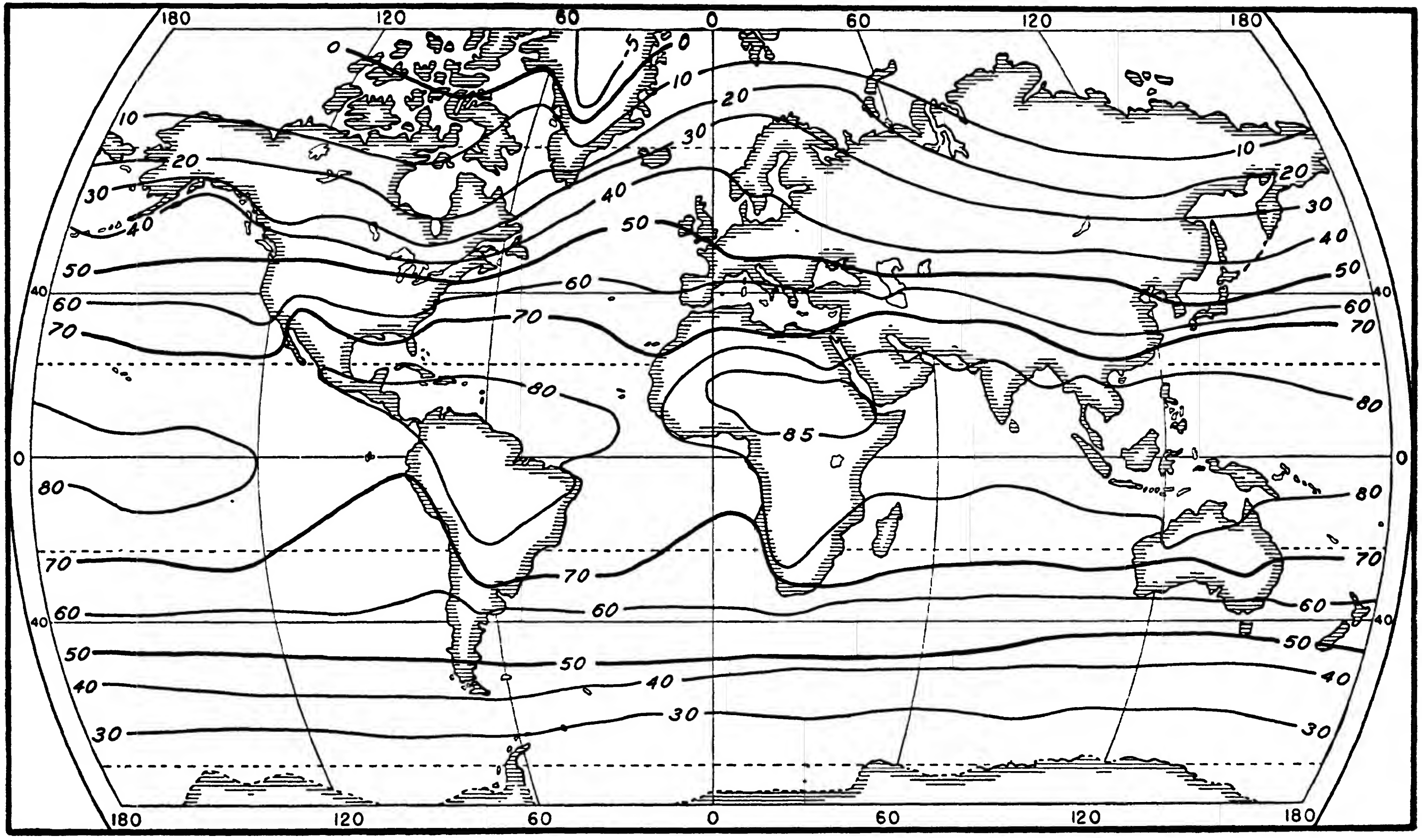

Fig. 5—Annual Mean Sea-level Temperatures, °F.

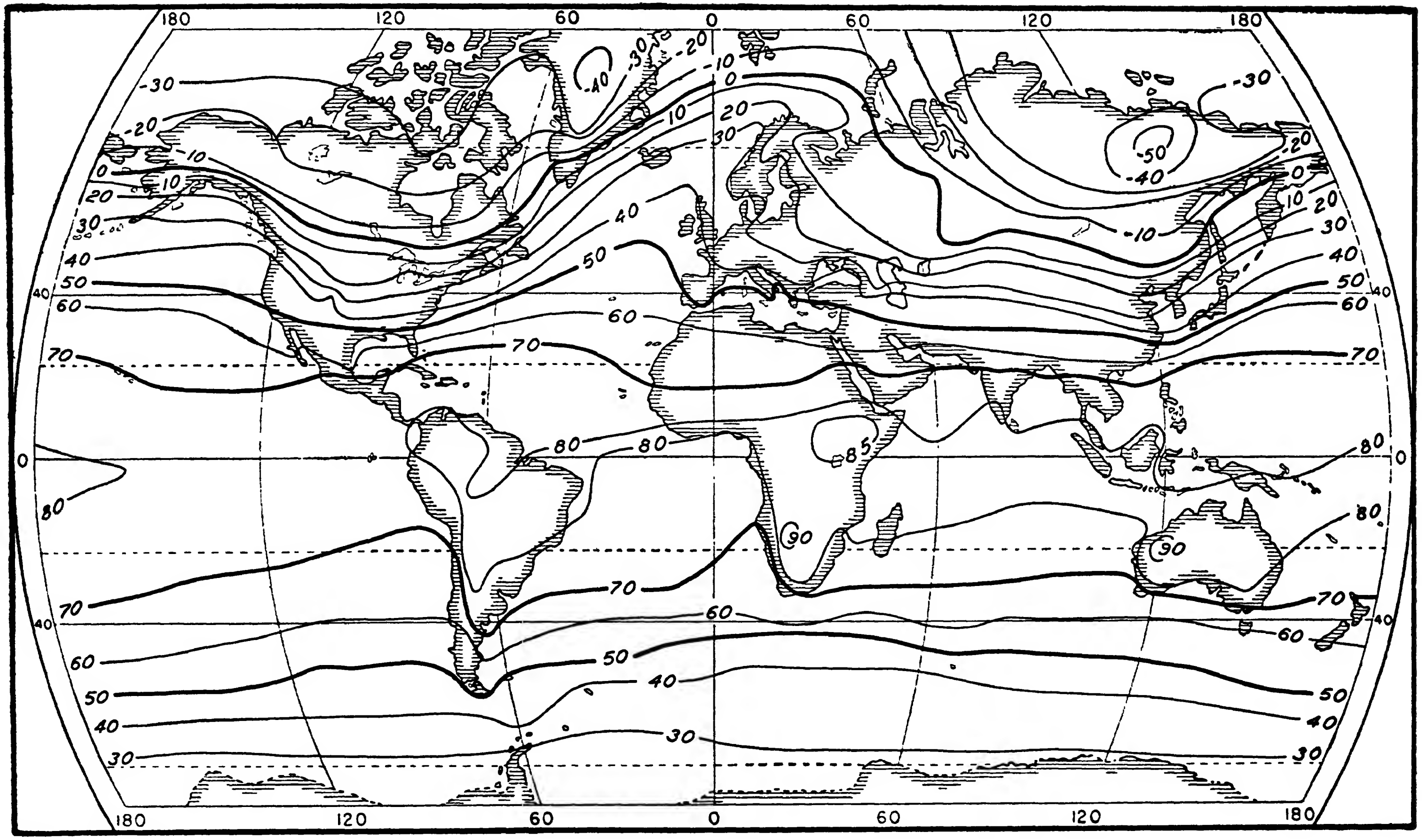

FIG. 6—January Mean Sea-level Temperatures, °F.

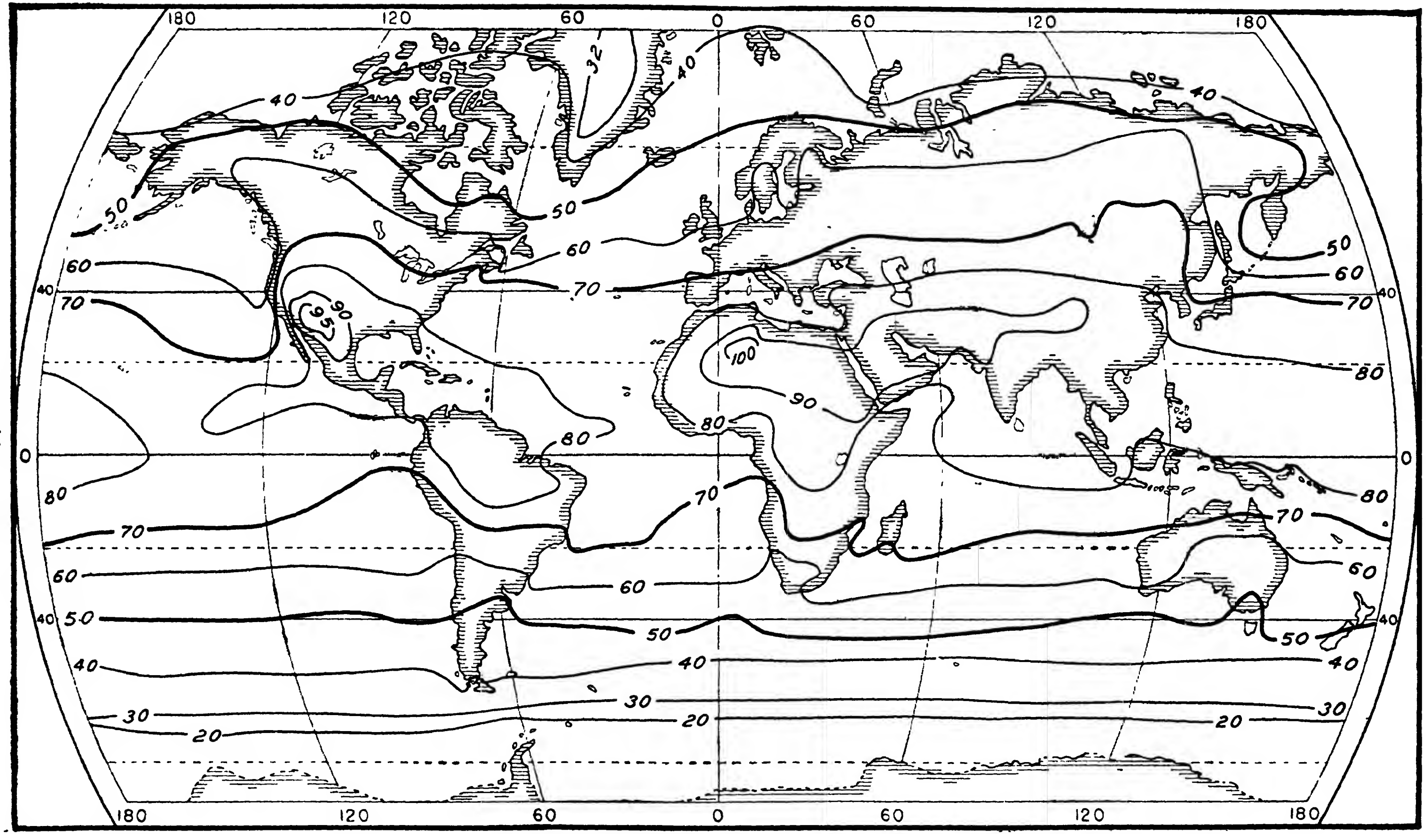

FIG. 7—July Mean Sea-level Temperatures, °F.

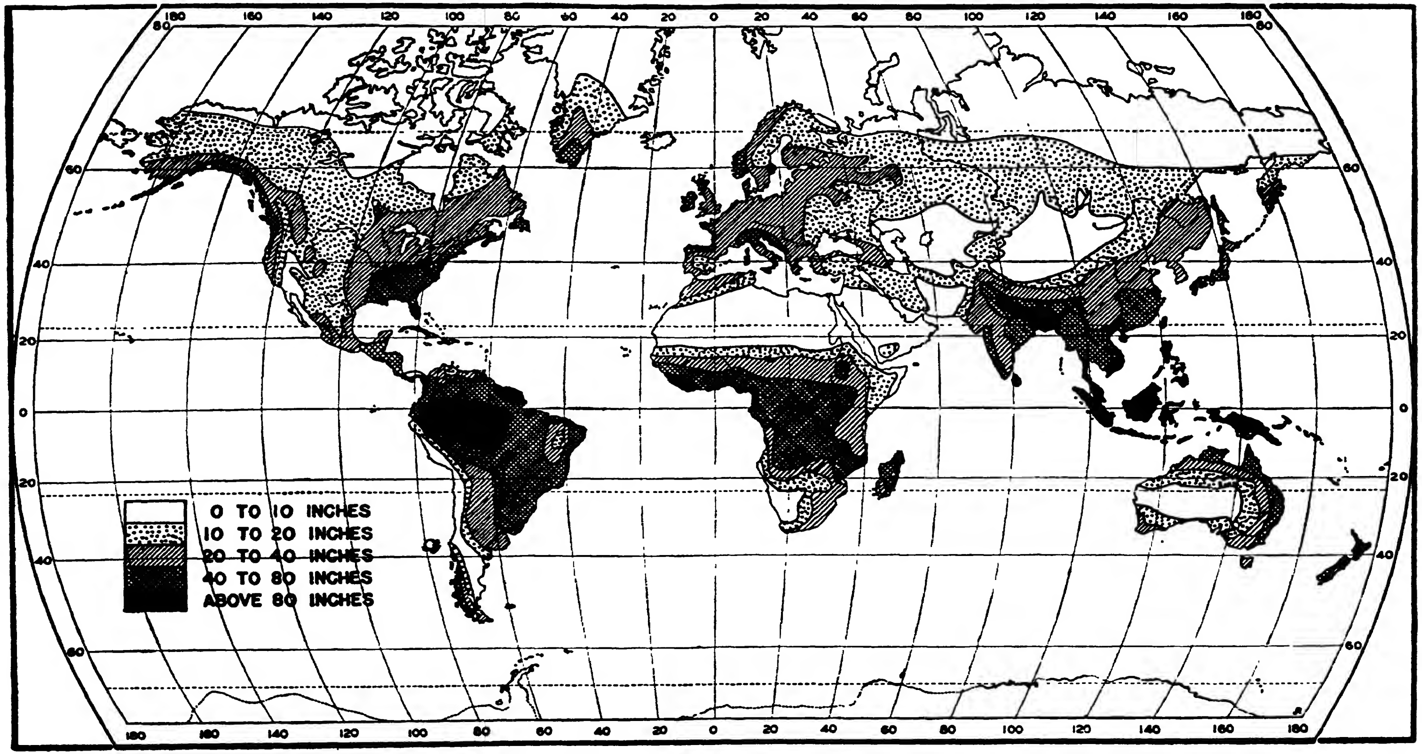

FIG. 8—Mean Annual Precipitation.

earth. Rainfall distribution is less systematic than temperature distribution. Amounts range from less than ten inches to more than eighty inches, and areas of very light and very heavy rainfall sometimes occur in close proximity. The following terms are used in describing the five subdivisions shown on the map:

Scant	0–10 inches
Light	10–20 "
Moderate	20–40 "
Heavy	40–80 "
Very heavy	Above 80 "

Latitude as a Climatic Control

With reference to temperature, the primary climatic control is latitude, for latitude, as we have seen, determines the relative amounts of heat received directly from the sun in the form of radiant energy. On the basis of latitude, or solar inclination, the earth is divided into five zones by the Tropics of Capricorn and Cancer and the Arctic and Antarctic Circles. In so far as the actual climate of a place is governed by its latitude—that is, by the insolation received by reason of its latitude—it is called *solar climate.* From the charts of the general distribution of temperature over the earth, it is evident that temperature is determined in broad outline by latitude. Despite considerable departures, the general trend of the isotherms is east and west—that is, latitudinal. All equatorial regions are hot because they receive large amounts of insolation, and all polar regions are cold because the annual amount of solar heat received is relatively small. It is also obvious that annual range of temperature is closely related to latitude. In tropical regions there is little seasonal variation in the amount of heat received from the sun, but with increasing latitude there is increasing difference between winter and summer insolation. Hence, the difference in temperature between the warmest and coldest months is always small in low latitudes, and tends to increase toward the poles. Precipitation also shows some relation to latitude; it is heavy near the equator and light within the polar circles. The hot and humid valleys of the Congo and the Amazon, and the glacier-covered highlands of Antarctica and Greenland are alike in owing their essential climatic characteristics to their latitude.

It is equally evident from these charts, however, that insolation

does not exercise complete control over either the temperature or the rainfall of an area. The mean January temperature at 60° north latitude varies from 40° in the Atlantic Ocean to —30° in Siberia. The mean rainfall along the Tropic of Cancer ranges from less than ten inches in Arabia to more than eighty inches in India. Obviously there are other factors influencing the actual climates of the world. These other factors are such physical facts as the wind and pressure belts of the atmosphere, the distribution of land and water, and the elevation of the land. The actual climate is, therefore, called the *physical climate,* as distinguished from solar climate.

Continents and Oceans as Climatic Controls

A highly important factor in modifying the effect of latitude as a control of climate is the existing distribution of land and water areas over the earth. We have seen that land surfaces warm more rapidly than water surfaces under the influence of incoming radiation, and cool more rapidly by outgoing radiation. By day and in summer the income usually exceeds the outgo, and lands become warmer than oceans. By night and in winter, when income is small or lacking, cooling is more rapid on land than on water.

Continental and marine climates

Except within the tropics, the air over the continents, as compared with that over the oceans, shows a greater *daily range of temperature;* the days are warmer and the nights cooler. This is due not only to the slow change of water temperatures, but also to the increased cloudiness and humidity at coastal and island stations. Attention has already been called to the fact that clouds and water vapor intercept both the incoming radiation by day and the earth radiation by night. In marine situations along the Pacific coast of the United States, some average daily ranges are: Seattle, 13°; Eureka, 11°; San Francisco, 12°; San Diego, 13°. In the interior we find such daily ranges as: Minneapolis, 18°; Valentine, Nebraska, 25°; Kansas City, 18°; Shreveport, Louisiana, 19°. The difference in the behavior of land and water in respect to temperature changes produces differences also in the *daily march of temperature.* Except where the daily march is interrupted by sea and land breezes, the time of occurrence of the daily maximum

and minimum is later in marine situations than in continental situations.

The climatic effects of seasonal differences in heating and cooling are evident in Figs. 6 and 7. In January the continents of North America and Eurasia, in middle and northern latitudes, are much colder than the oceans in the same latitudes; in July they are much warmer. In the Southern Hemisphere, land areas are small south of Capricorn, but the same influence may be seen, although it is not as pronounced. (The seasons are reversed, of course.) Within the tropics the days are of almost equal length throughout the year, and seasonal variations are slight, but land areas average somewhat warmer weather than the oceans. In high latitudes the cooling of the land during the long winter more than offsets the warming during the short summer, and continental interiors average for the year somewhat colder weather than do oceans in the same latitudes.

The difference between continents and oceans in the extent to which they change temperature with the seasons is clearly shown in a chart of *mean annual ranges of temperature* (see Fig. 9). Note that a large area of the north Atlantic Ocean, even far north of the Arctic Circle, has a difference of less than 20° between the warmest and coldest months of the year, whereas the range exceeds 80° in a part of interior Canada and 120° in Siberia. In the Southern Hemisphere, outside of the Tropics, the oceans have an annual range of about 10°, and even though the land areas are small, they are sufficient to increase the range to 30° in South America, South Africa, and central Australia.

These contrasts are shown also in Fig. 2. Winnipeg in the interior of a continent near latitude 50° N. has a minimum in January and a maximum in July with a range of 70°, showing a very rapid warming in spring and a rapid cooling in autumn. Paris, in only slightly lower latitude, has highest and lowest means in the same months as Winnipeg, but the difference between the months is 29°, less than half the range at Winnipeg. Paris shows the moderating influence of its nearness to the ocean. An oceanic climate in the trade wind belt is illustrated in the Honolulu curve of Fig. 2. February has a slightly lower mean than January; the maximum is in August, and even September is warmer than July; the annual range is only 7.6°.

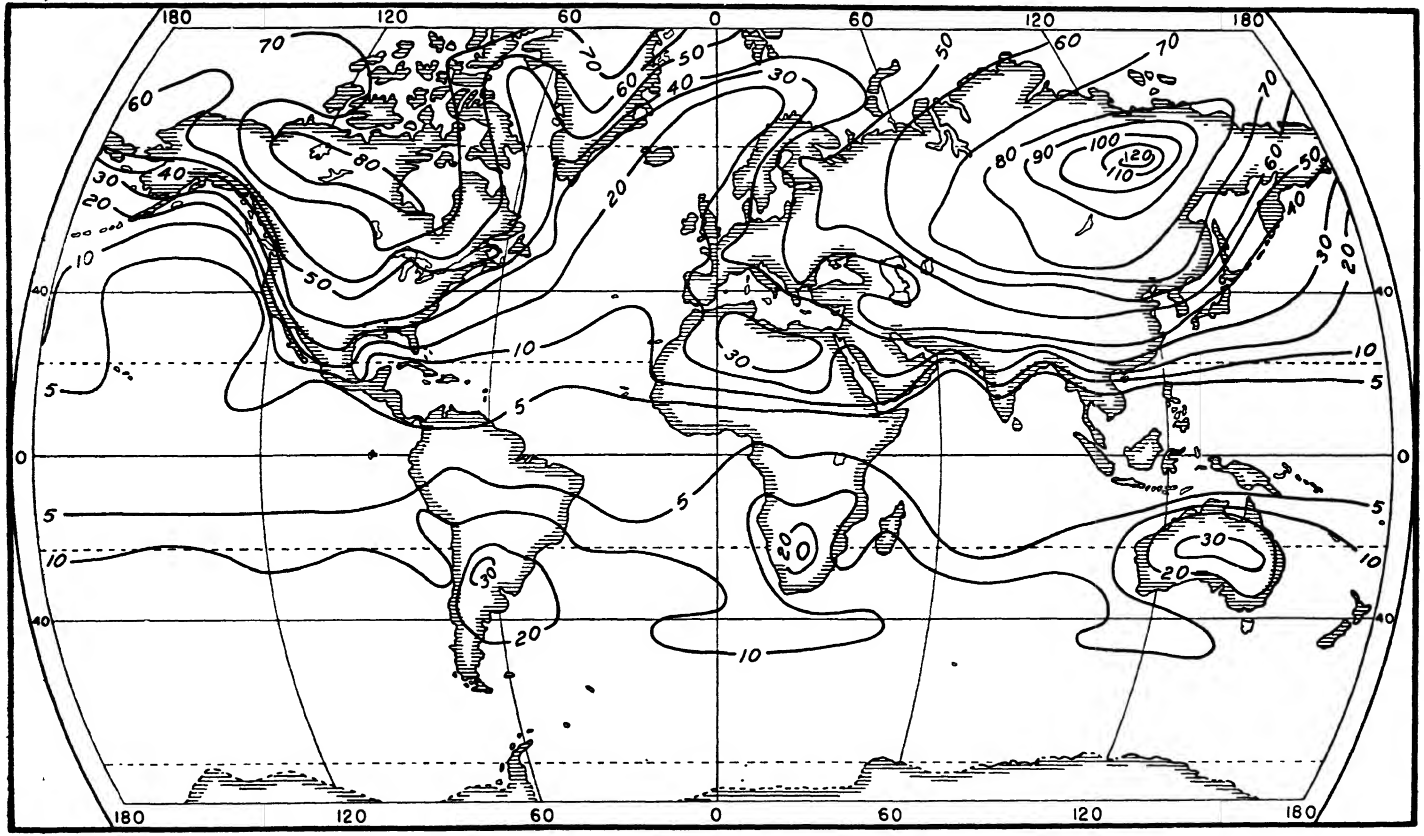

Fig. 9—Mean Annual Range of Temperature, °F.

The lag in the time of occurrence of the warmest and coldest parts of the year, as illustrated at Honolulu, is characteristic of oceanic climates, especially in middle and lower latitudes, and is the result of the slowness with which the temperature of water changes. A similar annual march of temperature is often evident near large lakes. In most continental situations July is the warmest month and January the coldest in the Northern Hemisphere; in the Southern Hemisphere the reverse is true. Thus the average times of greatest and least heat lag not more than a month behind the times of occurrence of the solstices. In marine situations the lag is often two months or more, making August or September the warmest month in the Northern Hemisphere and February the coldest.

In Figs. 10 and 11, curves are given for pairs of stations. The two stations in each pair have about the same latitude, but one is continental and one marine. Compare the times of occurrence of maximum and minimum temperatures, the annual ranges, and the shapes of the curves. Note that marine climates have a relatively cold spring and a warm autumn. At San Francisco, both September and October are warmer than July or August, and November has the same temperature as May. At St. Louis, November is 21° colder than May. San Francisco and St. Louis have nearly the same mean annual temperature, but only in April and October are the monthly means comparable. May and November temperatures are also equal at San Juan. At Khartoum, Anglo-Egyptian Sudan, a change of wind brings a short rainy season in July, August, and September, and keeps the temperature of those months below that of May and June.

Cloudiness and rainfall, as well as temperature, are directly affected by continents and oceans. Because of distance from the oceans, which are the chief source of atmospheric moisture, continental interiors usually have rather dry climates with low relative humidity, little cloudiness, and abundant sunshine. In contrast, marine climates are apt to be moist and cloudy, and often foggy. Fig. 8 shows that, for the most part, the central regions of continents are drier than the coastal areas. This is not true in all cases, and it is evident that other factors are important for their influence on rainfall. The distribution of cloudiness and humidity follows that of rainfall in a general way, especially in summer. In

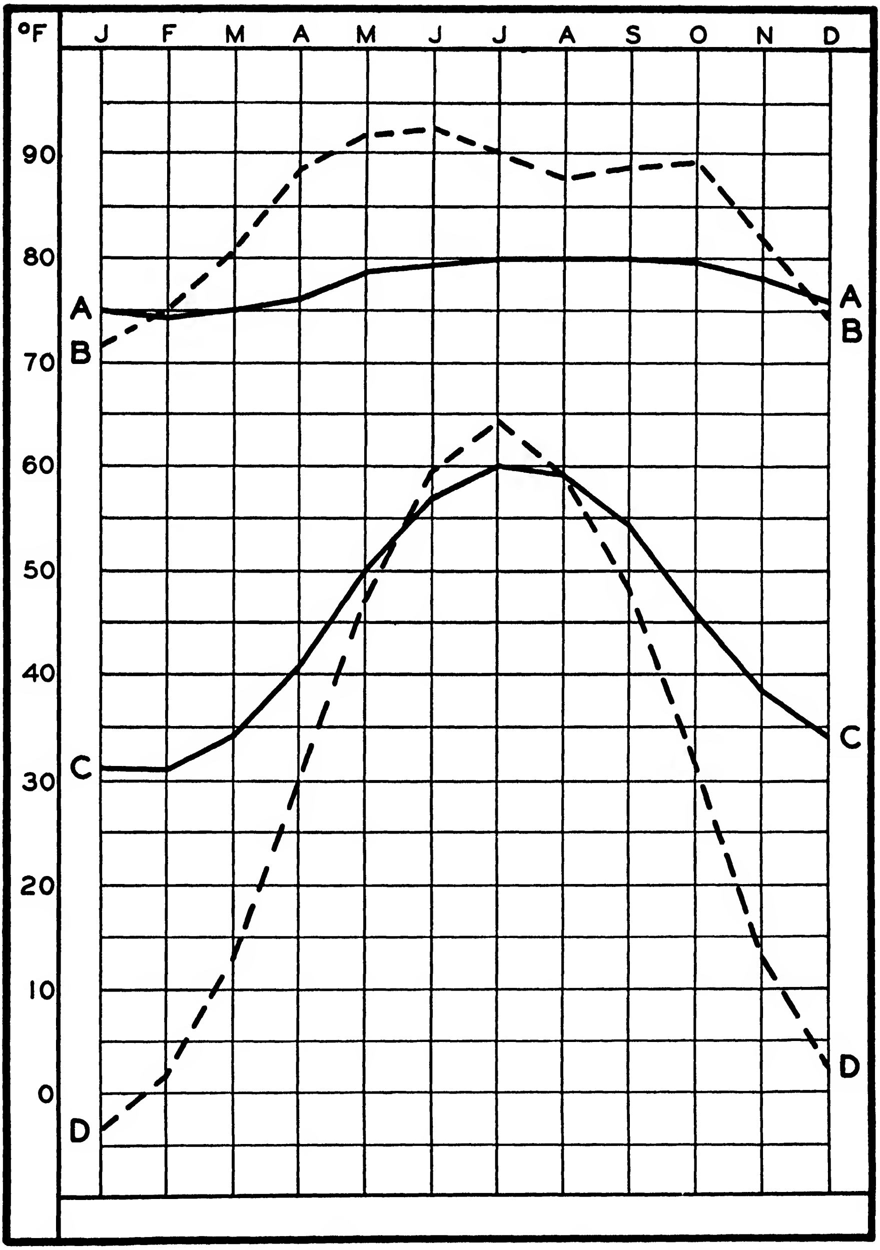

FIG. 10—Comparative Monthly Temperatures in Continental and Marine Situations.
A. San Juan, Puerto Rico, latitude 18° 29′ N.
B. Khartoum, latitude 15° 37′ N.
C. Copenhagen, latitude 55° 41′ N.
D. Tomsk, latitude 56° 30′ N.

winter, cold interiors of continents have a low absolute humidity, but the relative humidity may be high, resulting in considerable cloudiness but little precipitation.

Coastal climates

Marine influences are felt along the coasts of continents, and extend to varying distances inland. The climates which result

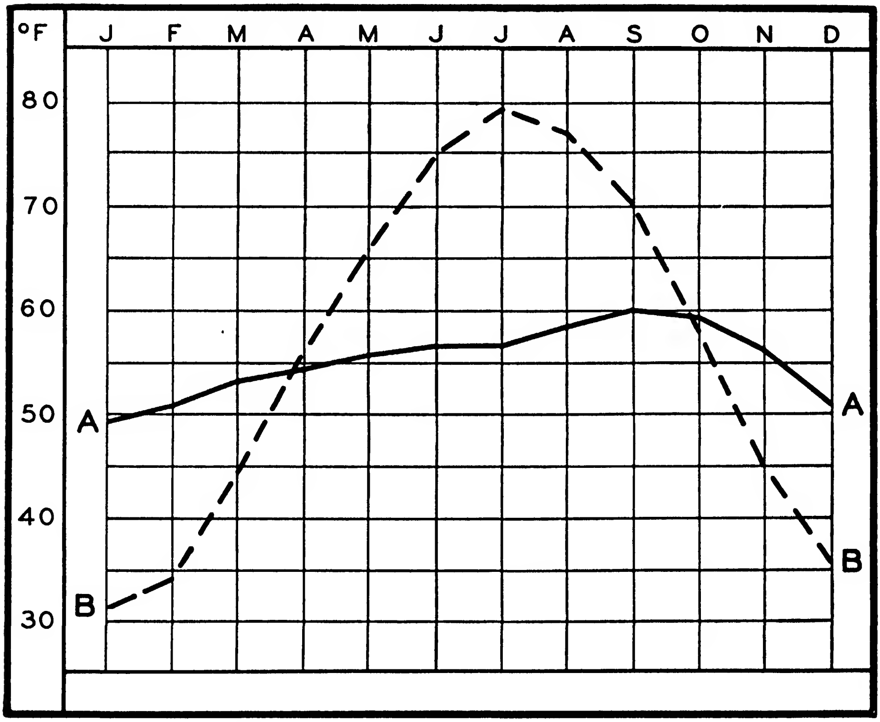

Fig. 11—Comparative Monthly Temperatures in Continental and Marine Situations.
A. San Francisco, latitude 37° 48′ N.
B. St. Louis, latitude 38° 38′ N.

from such mingling of continental and marine influences are known as *coastal,* or *littoral,* climates. The degree of the marine influence and the distance it extends inland are governed in the main by prevailing winds and by the elevation and configuration of the land.

On the western coast of the United States the prevailing westerly winds carry air from the Pacific over the land. West of the coastal mountain ranges, the climate is often called *marine;*

it is a coastal climate in which marine influences predominate. The interior valleys between the coastal mountains on the west and the Sierra Nevada and Cascades on the east have a climate which is much more modified by continental influences, but in which marine factors are also evident. These valleys have a truly intermediate type of climate. East of the Sierra Nevada and the Cascades, in Nevada and the eastern portions of Oregon and Washington, the climate is definitely continental; the mountain ranges have intercepted the oceanic influences. The western coast of Europe has no such transverse mountain ranges south of the Scandinavian Peninsula, and is, moreover, irregular and much indented. Hence, the westerly winds carry Atlantic air masses far inland, and even in central Europe the climate is modified by marine influences. Again, because of the eastward drift of the air in middle latitudes, continental influences extend to the east coast of the United States. The coast north of Florida, therefore, has no marine climate, and only a narrow strip of modified continental, or coastal, climate.

In South America, Chile has marine and coastal climates west of the Andes which are similar to those of the western coast of North America, and Argentina has a continental climate, but less pronounced than in North America because the South American continent is narrow in those latitudes. In trade wind latitudes the eastern coasts of land masses, because of the easterly component of the prevailing winds, are subject to marine influences, and the western coasts to continental influences.

Along many coastal regions, large differences in the temperature of adjacent land and water surfaces occur daily, and result in diurnal changes of wind direction. By day, especially on clear quiet days, the air over the land becomes much warmer than that over the ocean. The warmed air expands, becomes less dense, and is displaced by the cooler and therefore denser air from the ocean. This is the *sea breeze,* a movement of fresh marine air inland. It begins some distance offshore, usually in the forenoon, and moves inland during the day to distances of ten to thirty miles or more. It is especially marked in summer and in subtropical regions (as in California) where the general air movement is light, and where the land is highly heated by day, but it occurs also in much higher latitudes. In the latter case it is often modified or masked by

winds due to other causes. The sea breeze, which is one of the processes by which marine influences are brought to the land, is a characteristic of coastal climates.

Toward evening the sea breeze begins to subside, and after sunset the land begins to cool more rapidly than the water. As the air over the land becomes cooler than that over the water, a movement of air from the land to the ocean occurs. This is the *land breeze,* a night phenomenon, usually less developed than the sea breeze, because temperature contrasts are usually less by night than by day. Similar breezes, onshore by day and offshore by night, occur in the vicinity of large lakes such as Lake Michigan and Lake Geneva. In these instances the onshore wind is known as a *lake breeze.* An analogous seasonal shifting of the winds due to temperature contrasts between continents and oceans will be discussed, together with the general circulation, in the next section.

Continentality

Where there are no intercepting mountain ranges, marine influences decrease gradually inland to the center of a continent or to considerably beyond the center as measured in the direction of the prevailing winds. Usually, the larger the continent, the more pronounced is the continental character of the climate of its interior, and distance from the ocean is some indication of the degree to which continental influences predominate. Because of the influence of mountain barriers and prevailing winds, however, distance *per se* is not a good measure of continentality. It is the severe winters and hot summers of continental interiors in middle and higher latitudes, as compared with the relatively mild winters and cool summers of ocean areas in the same latitudes, that make the most important and most constant difference between continental and marine climates. Hence, the annual range of temperature, used with a correction factor for latitude, is a better measure of the continentality of a climate than is distance from the ocean.

Summary

Marine climates are moderate in their temperature changes, with small diurnal and annual ranges of temperature, pleasant summers, mild winters, late cool springs, late warm autumns, and often considerable cloudiness and high humidity. Continental cli-

mates have greater temperature extremes, more rapid changes in temperature, and, generally, drier and clearer air. Diurnal and annual ranges and irregular changes in temperature are large, and increase with increasing distance from the oceans. Coastal climates are intermediate in their characteristics.

Pressure Belts and Winds as Climatic Controls

Barometric records obtained through many years and in nearly all parts of the earth show that there are both permanent and seasonal differences of pressure over the globe, and, closely related to them, permanent and seasonal wind systems. Three major physical causes unite to produce and maintain the general system of pressure distribution and air movement. These causes are (1) the permanent differences in temperature between high and low latitudes which result in the movement of the surface air toward equatorial and away from polar regions; (2) the seasonal contrasts in temperature between land and ocean areas which cause air to accumulate over cold continents in winter and move outward at the surface, and to accumulate over the relatively cold oceans in summer and move landward; (3) the deflection due to the earth's rotation, which turns all moving air to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, and which prevents a direct, continuous movement of air between equator and poles.

The general circulation

The records show that the mean annual pressure is distributed over the earth in rather well-defined belts, and with these is associated a permanent wind system known as the *general circulation.* These pressure belts and winds are indicated in outline (omitting many of the isobars) in Fig. 12. But the annual distribution is modified by the changing seasons, especially by the apparent movement of the sun as the seasons change, and by the different temperatures assumed by land and water surfaces under the influence of incoming and outgoing radiation. The changes that occur between mid-winter and mid-summer are shown in the January and July charts—Figs. 13 and 15 for pressure changes, and Figs. 14 and 16 for corresponding wind directions. In all these charts pressure is reduced to sea level; otherwise the distort-

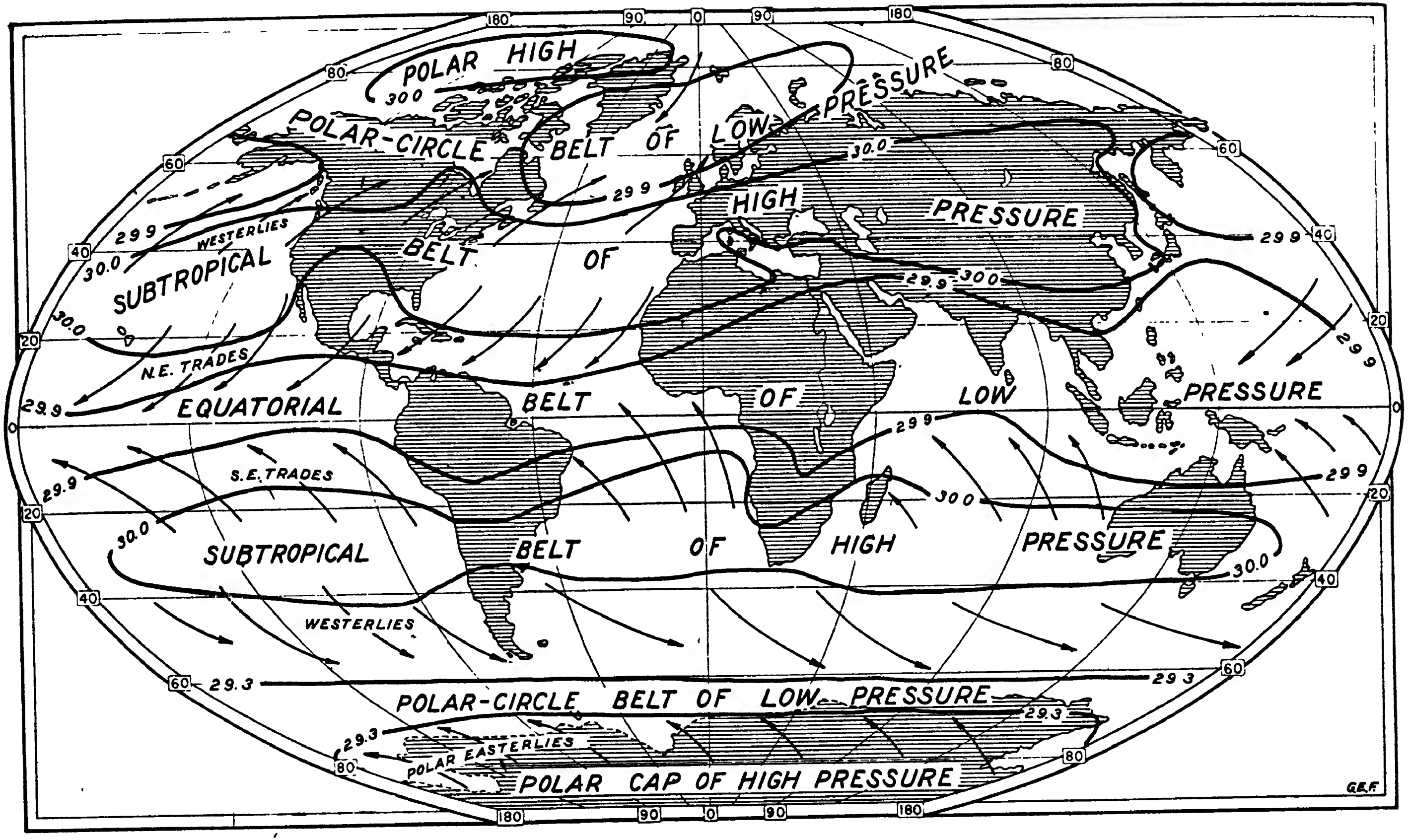

FIG. 12—Mean Annual Pressure Belts and General Wind Systems.

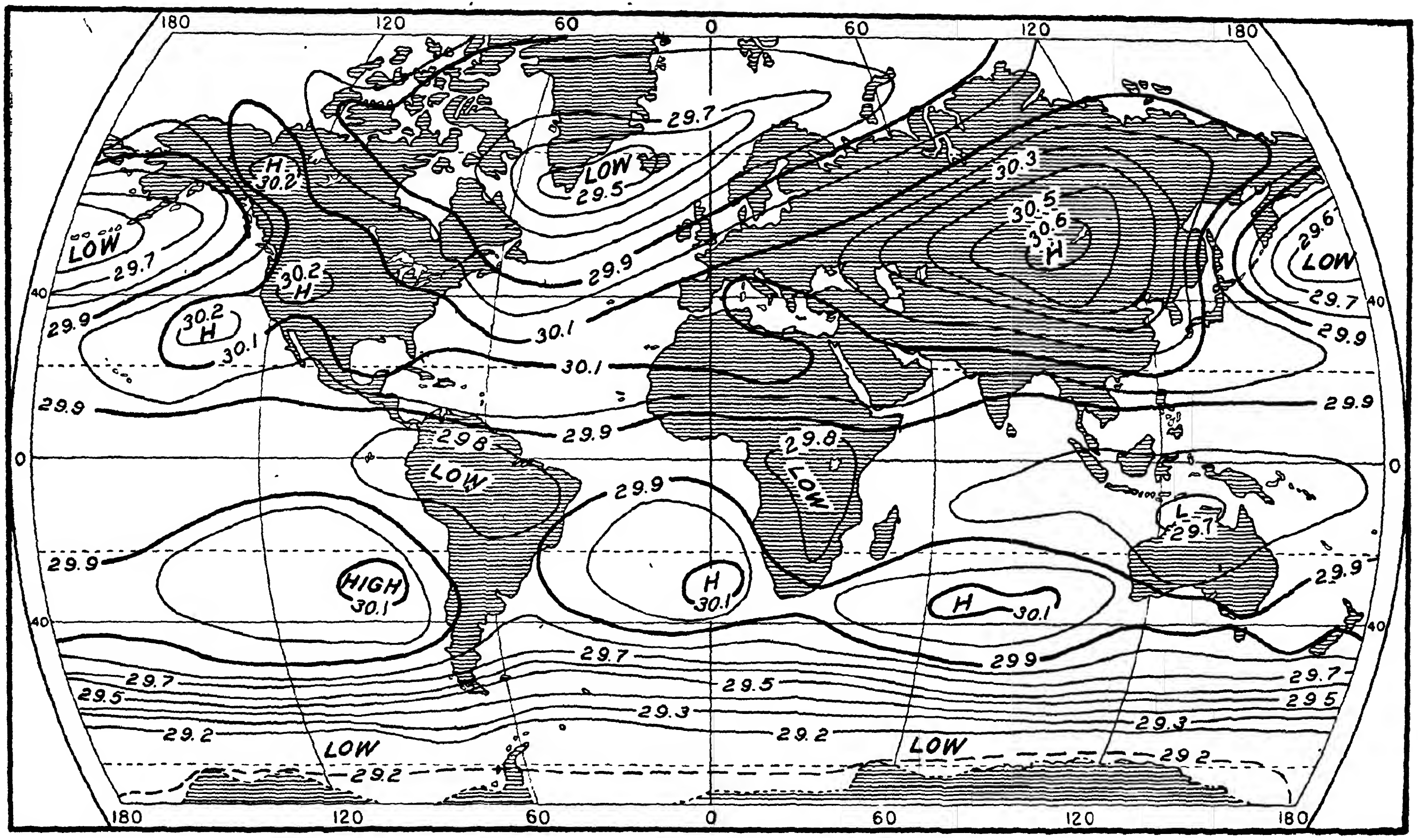

Fig. 13—Mean January Pressure Distribution.

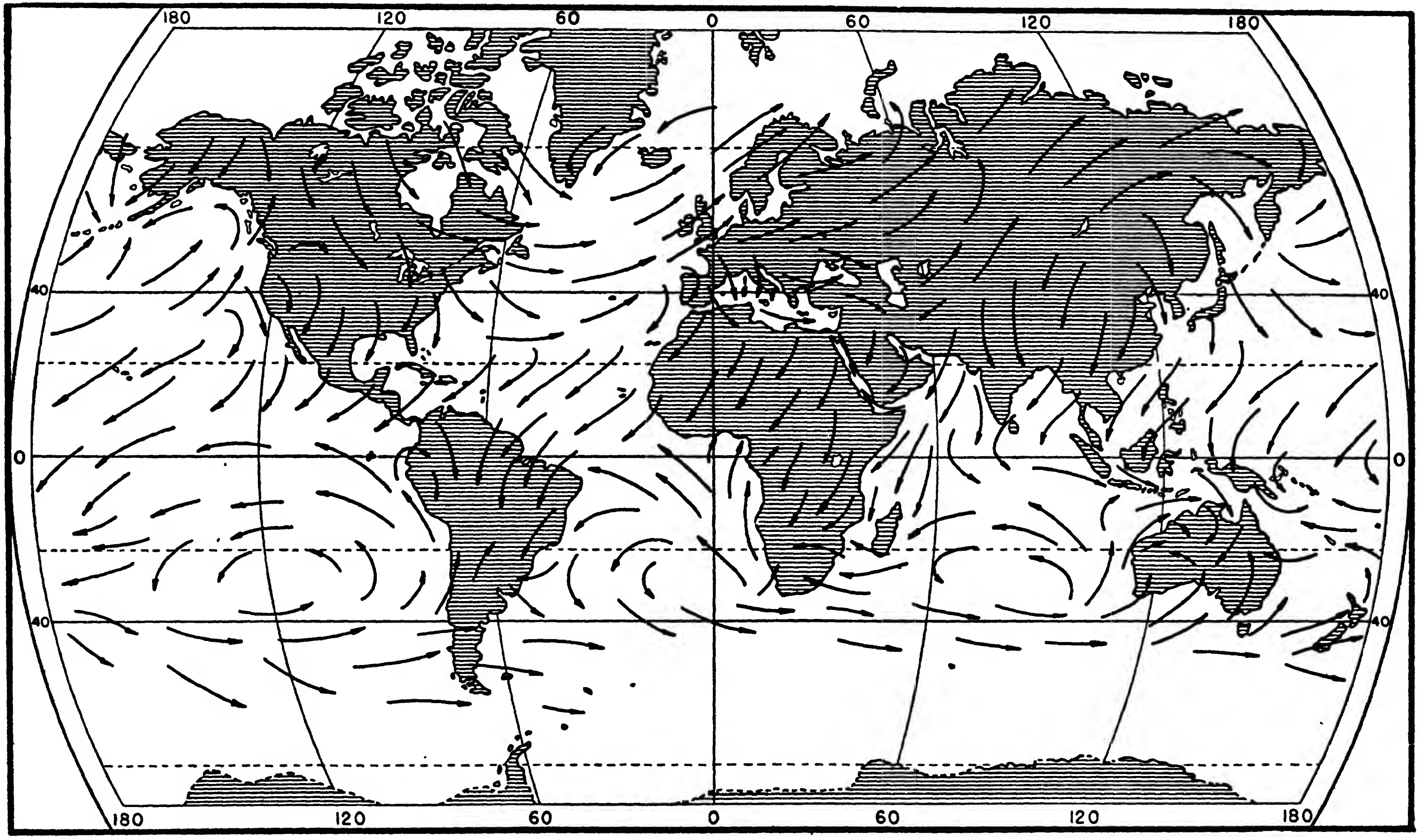

FIG. 14—Winds of the World, January. (Ocean data after W. F. McDonald.)

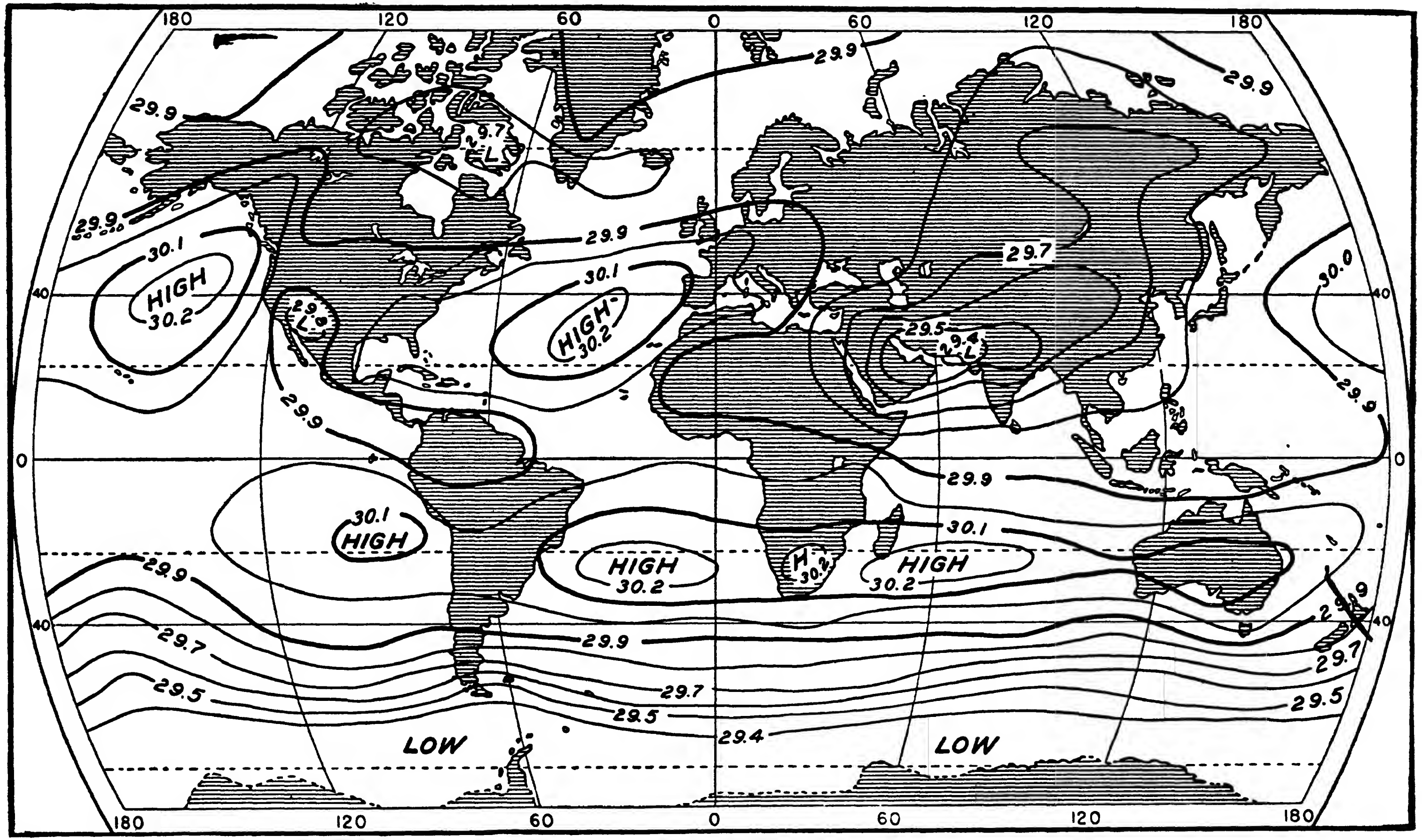

FIG. 15—Mean July Pressure Distribution.

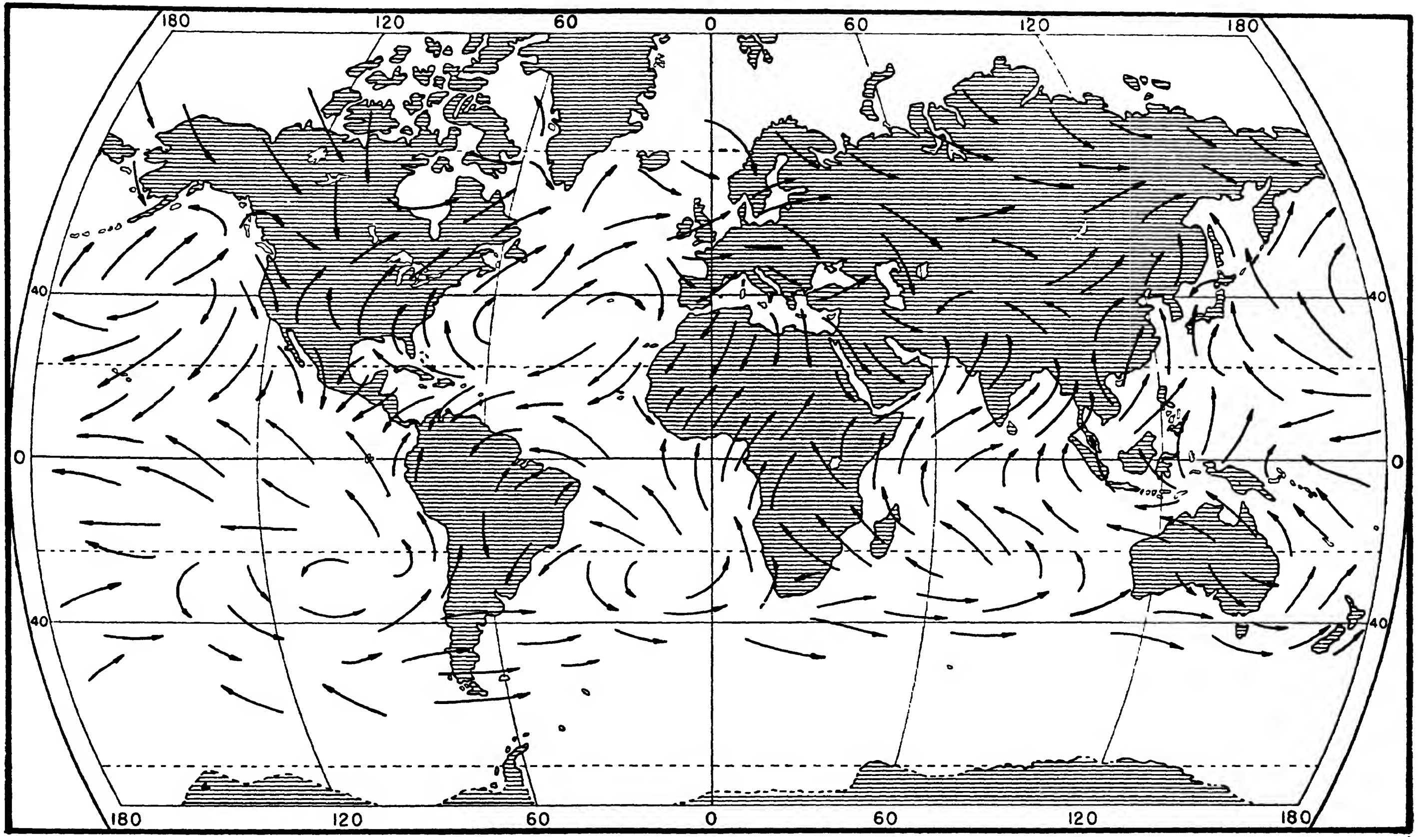

FIG. 16—Winds of the World, July. (Ocean data after W. F. McDonald.)

ing effects of elevation would mask the general conditions. Further, the charts represent average conditions; it must be kept in mind that winds and pressure distributions are complex in detail, and often show important variations from day to day.

Equatorial low-pressure belt

This belt of moderately low pressure is well-defined in the annual and January data, but becomes irregular in July, connecting with centers of low pressure over the heated interiors of southwestern North America and southwestern Asia. The equatorial belt is a region of warm and rising air and of light and variable winds with frequent calms. Humidity is high, rainfall is heavy, and thunderstorms are more numerous than in any other part of the world. In general, the climate is enervating and oppressive. All these conditions are most pronounced in the area of the *doldrums*—the narrow central area of the belt between the winds from the Northern and Southern Hemispheres. This doldrum area occurs between latitudes 5° N. and 5° S. but is mostly a little north of the equator.

Subtropical high-pressure belts

Centered at about latitude 35° N. and 30° S. there are belts of high pressure with dry, slowly descending air. These areas also have light and variable winds for the most part, but in winter they are occasionally invaded by storms from higher latitudes, resulting in a moderate winter rainfall. Because of the quiet, descending air, the summers are dry or rainless. The summer climates of the Mediterranean Region, southern California, and part of Chile are controlled by these subtropical high-pressure belts. Note that the centers of highest pressure are over the oceans in both hemispheres in July, except that the plateau of South Africa develops a center of moderately high pressure. In January, pressure becomes very high over the cold interior of Asia (Siberia) and moderately high over North America.

Polar circle low-pressure belts (subpolar lows)

Belts of low pressure are found in the vicinity of the Arctic and Antarctic Circles. Such a belt is well-defined and regular at all seasons in the Southern Hemisphere, which is a uniform water

surface in those latitudes (see Figs. 12, 13, and 15). In the Northern Hemisphere it will be noted that the belt is more irregular and tends to break up into separate centers. In January there are two strongly developed centers of low pressure in this belt; one is known as the *Aleutian Low* and extends from Siberia to Alaska; the other is known as the *Iceland Low* and covers much of the northern Atlantic. The strong temperature contrasts between adjacent land and water areas contribute to the development of these low pressure areas over the northern oceans in winter. In July the temperature differences between land and water are less than in January, the belt is more nearly uniform, and the pressure is not as low as in winter.

Polar caps of high pressure

The continuous cold of glacial or permanently frozen regions around the poles results in the accumulation of masses of dense air and the formation of caps of high pressure over Greenland, the Arctic Ocean, and Antarctica. At the surface, air flows out of these cold caps toward the equator, and is deflected to the west, becoming a northeast wind in the Northern Hemisphere and a southeast wind in Antarctic regions. These winds are known as the *polar easterlies.*

Trade wind belts

Blowing out of the subtropical highs toward the equatorial low, there are steady moderate winds (ten to fifteen miles per hour) known as *trade winds.* These winds are from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere. The northeast trades are strongest and steadiest between the Tropic of Cancer and 5° N. latitude on the east and south sides of the oceanic centers of high pressure. In January they extend well across the oceans, but in July the winds become southeasterly on the western sides of the oceanic highs of the Atlantic and Pacific, as, for example, along the Gulf and south Atlantic coasts of the United States, and on the southeastern coast of Asia. In the Southern Hemisphere the southeast trades are best developed on the east and north sides of the oceanic highs, and winds become northerly at places on the west sides of the oceans, as is true off the east coasts of South Africa and southern Brazil.

The trade wind climate is remarkably simple and uniform, especially at sea and over the many small islands within the belt. There is an absence of storms, the same gentle breezes blow day after day, and temperatures are mild both day and night, both winter and summer. The air is moving from higher to lower latitudes, its temperature is rising, and therefore its relative humidity remains moderate even when it moves over a warm water surface. The climate is monotonous and not stimulating, but it is comfortable and healthful, and not at all like the equatorial climate of the doldrums. The skies are clear and rainfall is light except where mountains force the air to rise. Where mountains rise athwart the trades, the windward sides often have almost continuous rain, and the lee sides approach desert conditions. The Azores, the Hawaiian Islands, and some of the south Pacific islands have typical insular trade wind climates. In general, the trade winds are not in evidence over large continental areas, but many of the desert and semiarid regions of the world are in the latitude of the trade winds and the subtropical highs. In both cases the air is naturally dry because of increasing temperature. The greatest desert of all, the Sahara, has the trade winds across its entire length.

Tropical cyclones

Although ordinarily free of high winds and stormy weather, the trade wind belts are occasionally invaded from their poleward sides by the storms of middle latitudes, and on their equatorial

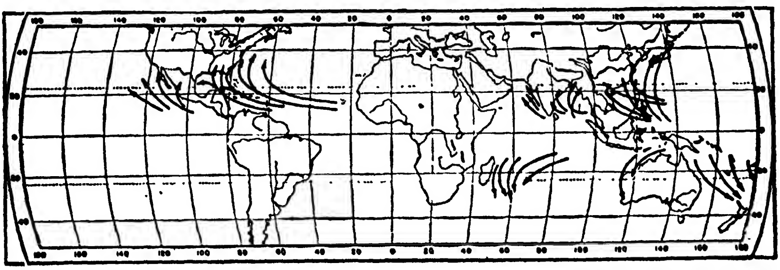

FIG. 17—Regions and Generalized Paths of Tropical Cyclones.

sides by the destructive storms known as *tropical cyclones* (called *hurricanes* in the West Indies and *typhoons* in the western Pacific Ocean). These are revolving storms, 300–600 miles across, with low pressure and violent winds near their center, and "wasting and destruction are in their path." They originate over the oceans

near the boundary of the trade winds and the doldrums, when these are farthest from the equator—that is, in late summer and autumn—and they move slowly westward, gradually curving away from the equator. Although comparatively infrequent in any one locality, they are an outstanding feature of the climate in certain regions on the western sides of the oceans near the Tropics of Cancer and Capricorn. They disintegrate over land and never move with destructive energy far inland. The six general regions where most tropical cyclones occur are: (1) from the Bahamas to the Caribbean Sea and the Gulf of Mexico; (2) in the Pacific Ocean west of Mexico; (3) in the western Pacific in the neighborhood of the Philippines and the China Sea; (4) in the Bay of Bengal and the Arabian Sea, where they occur in the calm seasons of spring and autumn; (5) in the southern Indian Ocean east of Madagascar; and (6) in the south Pacific from the vicinity of Samoa and the Fiji Islands westward to northern and western Australia.

The prevailing westerlies

Air moving out of the poleward border of the subtropical highs toward the Polar Circle belts of low pressure is deflected to the east in each hemisphere, and forms what are known as the *prevailing westerly winds.* These winds come from directions between west and southwest in northern latitudes and between west and northwest in southern latitudes. (See Fig. 11.) This belt of prevailing westerlies lies roughly between latitudes 35° and 60° in each hemisphere, and includes chiefly the intermediate climates of the globe. It is the home of the greater part of the most vigorous and progressive peoples of the world. The climate of the belt is characterized by great inconstancy of weather and by considerable storminess of moderate intensity. The frequent changes of weather in these middle altitudes are associated with frequent disturbances in the smooth flow of the westerlies; this is explained in the following discussion of air masses and of the genesis of cyclones and anticyclones.

Monsoons

Mention has been made of the shifting of the pressure belts and of the general circulation with the changing elevation of the sun,

and of the influence of continental and oceanic areas upon the pressure distribution. The most striking example of the climatic results of such influences is seen in the Indian Ocean and in south and east Asia. In January, decidedly high pressure develops over central Siberia, and the doldrums are somewhat south of the equator in the Indian Ocean (see Fig. 13). Steady northeast winds therefore blow out of Asia in an anticyclonic circulation across the Indian Ocean to the equator (Fig. 14). In July there is low pressure over interior Asia, and there is a continuous gradient of pressure toward this low from the subtropical belt of high pressure in the south Indian Ocean. Hence southwest winds from the ocean move across southern Asia to the interior (Figs. 15 and 16).

Other continental areas that become cold in winter and hot in summer show similar changes in pressure and similar outward movements of air in winter and inward movements in summer. In no other region, however, are these seasonal reversals of wind directions so well developed as in India and the Indian Ocean. Winds of this character are called *monsoons.* They give a distinct character to the climate of India and southeastern Asia. In a monsoonal climate the winters are characteristically dry and cool, since the *winter monsoons* come from a cold land area and move toward warmer latitudes. The *summer monsoon* brings warm, moist marine air to the land, and summer is the season of highest humidity and maximum rainfall.

Air masses

The movement of air in the belt of the prevailing westerlies is far from regular and steady. Instead, there is an unending series of irregular movements northward and southward, superimposed upon a general drift from west to east. Inequalities of the temperature and the moisture of the air are the chief causes of these seemingly erratic movements. The temperature and moisture of the air near the surface of the earth depend largely upon the condition of the surface over which the air moves. Air that is quiescent or slowly-moving over a dry, cold land surface becomes cold and dry itself. On the other hand, air becomes warm when it overlies a warm surface, and it takes up much moisture over a warm water surface. It is thus that air masses are formed.

An *air mass* may be defined as a large body of air of almost uni-

form physical properties—especially as regards temperature and water vapor—at the same elevation. Air masses are divided into four main types, according to the character of their source regions: (1) those that originate over land in high latitudes, but not necessarily polar latitudes, are cold and dry and are called *polar continental* (cP) air masses; (2) those having their source over cold ocean waters are moderately cold and moist, and are named *polar maritime* (mP); (3) *tropical continental* (cT) air masses form over warm or hot land areas in low latitudes, but not necessarily within the tropics, and are warm and dry; (4) *tropical maritime* (mT) air masses are warm and moist because they originate over warm oceans. A fifth type of air mass, known as *superior* (S) air, is of some importance. It is formed by subsidence of the upper air, and it is warm and dry (relative humidity less than 40%).

These are the more important types of air masses which affect the climate of middle latitudes. Sometimes they move outside of these latitudes. Although the interaction of air masses is most evident in the prevailing westerlies, it is not confined to this belt. The quiet doldrum regions near the equator are the source of *equatorial* (E) air masses. Equatorial air masses have a higher temperature and a higher moisture content than tropical air masses, and their unstable condition favors convective movements and thunderstorms. Within the polar circles, bodies of air develop that on the whole are colder than polar air. These are called *arctic* (A) air masses, and they have an influence on the climate of high latitudes, particularly in the northern portions of Europe and Asia.

Air masses do not remain indefinitely in the places of their origin, but move irregularly into other regions, thereby greatly influencing weather and climate. For example, cold and dry air often accumulates in the Northwest Territory of Canada in winter and then moves southward and eastward across the United States as a polar continental air mass, attended by clear and cold weather. Such outbreaks of polar continental air are sufficiently frequent to give the northern states from the Rocky Mountains eastward a severe winter climate. Similarly, tropical maritime air masses move northward from the Gulf of Mexico into the interior and eastern portions of the country, and bring warm and humid weather with them. Polar maritime air arrives on the west coast of North

America from the north Pacific Ocean, and on the east coast from the north Atlantic. Hot and dry air having tropical continental characteristics sometimes moves northeastward from the dry regions of Arizona and New Mexico. In Great Britain and western Europe, cold air masses come with east or northeast winds from the European interior in winter, and warm air masses come with southwest winds from the Atlantic Ocean. It is evident that the frequency of the occurrence of different air masses at a given locality is an important characteristic of its climate.

Fronts and cyclones

In another respect the movement of air masses is important climatically. The moving bodies of air from different sources inevitably meet somewhere, mainly within the belt of the westerly winds. The surface along which they come in contact is called a *surface of discontinuity,* or a *front.* The interaction of the differing air masses along a front results in the birth and growth of an extra-tropical cyclone (also called *barometric depression, barometric disturbance,* and *low*), and is chiefly responsible for the frequent changes of weather in middle latitudes and for a large part of the rainfall (that part which is called *cyclonic rain*).

The genesis and development of a cyclone are illustrated in Fig. 18. In part *a* there is shown a front between a cold air mass on the north and a warm air mass on the south. In this front a slight wave has developed because of some irregularity. The eastern part of the front has become a *warm front*—so called because the warm air is advancing eastward and overrunning the colder, denser air. This forced ascent of warm air is producing a small area of cloudiness or rain, as is indicated by the shading. The wave, once started, usually continues to develop, and is shown in *b* as a fully developed young and active cyclone. It has a warm front extending southeastward, and a large area of cloudiness and rain to the east of the front where the warm air is moving upslope over the colder air, as is shown in vertical section in *e*.

A *cold front* on the southwest marks the line along the ground at which the cold air is overtaking, underrunning and pushing up the lighter air and causing a narrow band of cloudiness and showers. On the south, between the two fronts, is a large sector of warm air. As the development continues, the cold-front ap-

proaches the warm front, as is shown in *c;* finally (*d*), the northern portions of the two fronts unite and lift the warm air off the ground, forming what is called an *occluded front,* which is shown by the dotted line. The supply of warm air to the center of low pressure is shut off by the union of the fronts, and the cyclone then begins to disintegrate.

As such a cyclone moves across a given area, the following succession of weather changes occurs (see the vertical section): first,

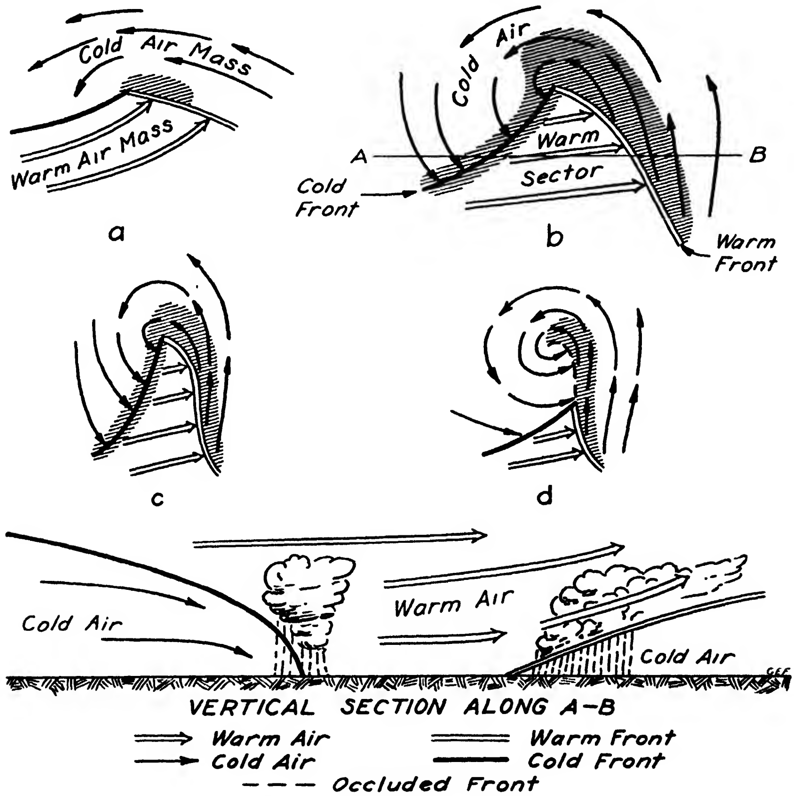

FIG. 18—Life Cycle of a Traveling Wave Cyclone.

there are high, thin clouds considerably ahead of the warm front, then increasing cloudiness and steady rain as the warm front approaches. With the passage of the front, there is a change in wind direction, an increase in temperature, and usually a cessation of the rain, but scattered clouds may be present in the warm sector, and sometimes scattered showers occur. The arrival of the cold

front is marked by a rapid development of dark, heavy clouds, the occurrence of showers and thunderstorms, and a sudden shift in the wind direction from southerly to northerly (in the Northern Hemisphere) attended by a sudden drop in temperature and a rise in pressure. The cold front is usually followed after a few hours by clear and cool or cold weather.

The movement of air spirally around the center of a depression is called a *cyclonic circulation.* The movement is counter-clockwise in the Northern Hemisphere and clockwise south of the equator. These barometric disturbances are carried along by the eastward drift of the westerlies, and, accordingly, they have a general direction of movement from west to east. Such disturbances are, however, subject to much shifting northward and southward. The rates of advance vary greatly in individual cases, but average twenty to thirty miles per hour. In size they range from 100 to 2,000 miles across. In the Northern Hemisphere, cyclones are more frequent and better developed in winter than in summer because of the greater temperature contrasts in winter. In the Southern Hemisphere there is little land in middle latitudes, seasonal changes are small, and there is little difference in storminess between winter and summer.

Anticyclones

Between the depressions formed by the meeting of air masses, there are areas of higher pressure, consisting of a single polar air mass, and the weather is therefore generally clear and cold. From the center of such areas the air moves spirally outward, clockwise in the Northern Hemisphere and counter-clockwise south of the equator. These areas are *anticyclones,* or *highs,* and the circulation around them is said to be *anticyclonic.* Highs and lows often follow each other in regular succession, but the highs are more likely to become stationary or to spread slowly. Hence, their average velocity is less than that of the lows, and their average size is greater.

Summary of wind effects

The general distribution of pressure over the world into alternating belts of high and low pressure, and the related general wind systems are obviously of fundamental importance in the control of climate. The winds transport great quantities of heat and mois-

ture from one portion of the globe to another. Were it not for these air movements, tropical regions would be much hotter and polar regions much colder than they now are. The irregularities and disturbances in the general circulation bring about their special modifications of climate. The climate of certain parts of the trade wind belts is modified by the occurrence of tropical cyclones; monsoon winds produce special climatic types; cyclones and anticyclones of the westerly winds give to middle latitudes the characteristic changeableness of their weather—the great variability from day to day of temperature, winds, cloudiness, and sunshine.

CHAPTER V

Climatic Controls—Continued

Ocean Currents as Climatic Controls

Progressive movements of their surface waters occur in all the oceans, largely in response to wind action. These ocean currents have an important influence on the climate of the world and on the distribution of the different climatic types. There are also deep, subsurface currents in the ocean. These are produced by differences in the density of the water, due to differences in its temperature or salinity, or both. The details of these subsurface movements are not known, but such currents probably have little direct climatic significance.

There are two types of surface currents. (1) When the wind blows predominantly from the same general direction for a prolonged period over a wide expanse of water, the friction at the surface produces a slow and shallow drift of the surface water known as *drift current*, or *drift*. As a resultant of the frictional forces and the deflection caused by the earth's rotation, the direction of such drift currents is 45° to the right of the wind direction in the Northern Hemisphere and 45° to the left in the Southern Hemisphere. These currents range in depth from 150 to 800 feet, and their speed is generally less than one mile per hour. (2) Winds blowing directly or obliquely onshore move the surface water shoreward, and there is a resulting tendency to an accumulation of water along the coast. This is particularly effective in raising the level of the water if the coast is an irregular one with bays and inlets. Winds with an offshore component result in a withdrawal of water from the coast. The differences in the levels of the ocean surface resulting from such accumulation or removal of water produce currents known as *gradient currents.*

Gradient currents are stronger and deeper than drift currents, and their speed is three to seven miles per hour. They are especially developed when favored by the configuration of the coast

line. For example, the shape of the Gulf of Mexico tends to confine the water brought to it by the trade winds and the Mississippi River, and thus the level of the Gulf is a few feet higher than that of the open Atlantic. As a result of this gradient, a stream of water flows from the Gulf into the Atlantic through the Florida Strait. Most of the other major ocean currents are also gradient currents. When gradient currents move along an extended coast line, they are strongest some distance offshore—near the continental shelf where the water becomes rapidly deeper.

General scheme of ocean currents

The relation of drifts and currents to winds and to the earth's deflective influence is evident by a comparison of Fig. 19 with Figs. 14 and 16. Around the oceanic high pressure areas in both hemispheres there are similar anticyclonic movements of winds and ocean waters. Around the only permanent center of low pressure over the oceans, the Iceland Low, there is a cyclonic circulation both in the water and in the air. The result is that between latitudes 40° N. and 40° S. the warm water of the equatorial drifts approaches the eastern shores of the continents, and cold water moving from higher to lower latitudes flows along the west coasts. North of latitude 40° N. warm water crosses the Atlantic and Pacific Oceans to the west coasts of Europe and North America, and cold water flows southward near the east coasts. In the Southern Hemisphere there is less warm water to move eastward, since more than half of the equatorial drift is in the Northern Hemisphere. What does move east south of the equator is lost in the great *Antarctic Drift* of cold water. Hence, southern Chile is washed by cold rather than warm water.

In the Atlantic Ocean, much of the water moving westward in the broad *Equatorial Drift* turns northward along the northeastern coast of South America, and a part of it enters the Caribbean Sea and the Gulf of Mexico, from which it emerges through the Straits of Florida as the *Gulf Stream.* The Gulf Stream is the greatest and most clearly defined of "ocean rivers," and it is able to maintain its identity and direction when, during the winter months, it moves for some distance against the prevailing direction of the winds off the southeastern coast of the United States. It then turns northeastward, and, under the name of the *Atlantic*

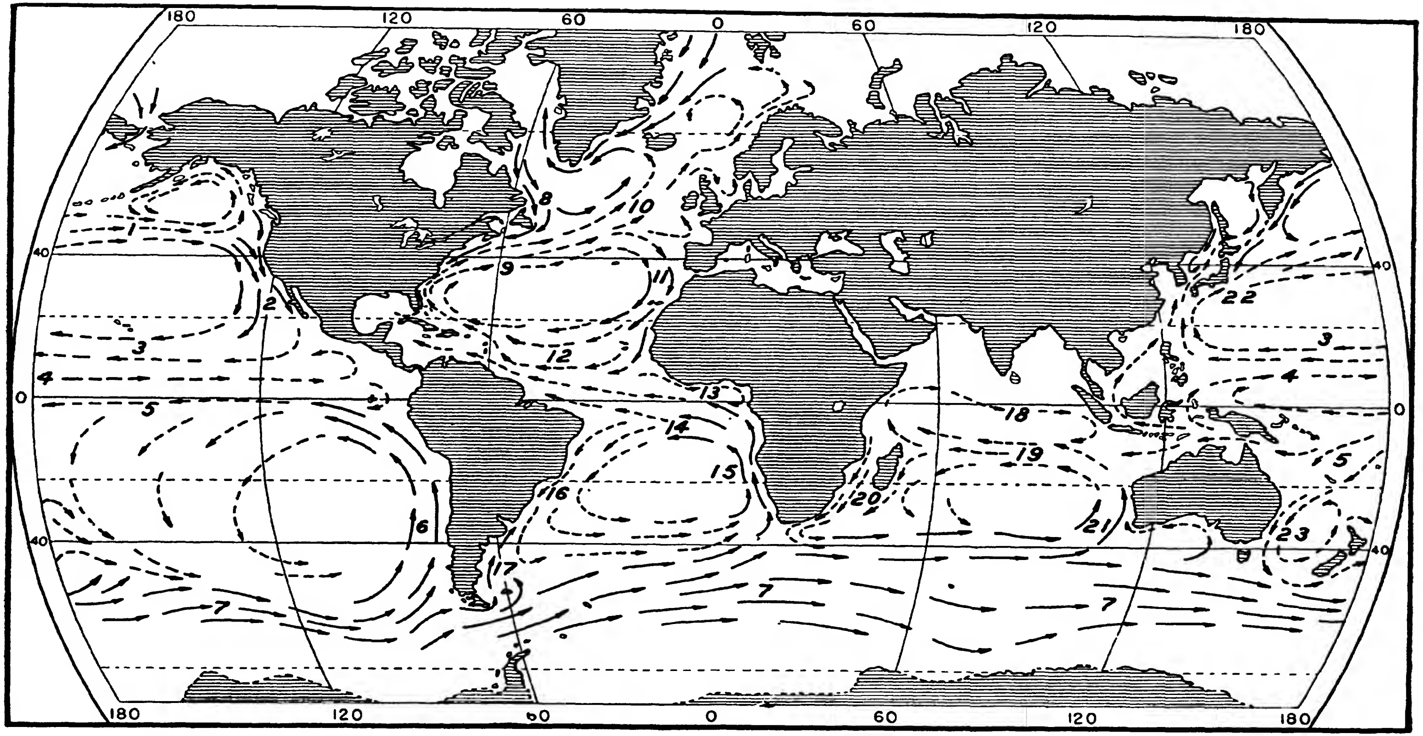

FIG. 19—Surface Currents and Drifts of the Oceans. Broken lines represent warm currents; continuous lines, cold currents. The numerous seasonal variations of direction are not shown. (1) West wind drift of north Pacific. (2) California current. (3) North equatorial current (Pacific). (4) Equatorial counter current (Pacific). (5) South equatorial current (Pacific). (6) Peru (Humboldt) current. (7) West wind drift of Southern Hemisphere. (8) Labrador current. (9) Gulf Stream. (10) North Atlantic drift. (11) Canaries current. (12) North equatorial current (Atlantic). (13) Guinea current. (14) South equatorial current (Atlantic). (15) Benguela current. (16) Brazil current. (17) Falkland current. (18) Indian Ocean counter current. (19) Equatorial current (Indian Ocean). (20) Mozambique current. (21) West Australian current. (22) Kuro Shio (Japan current). (23) East Australian current.

Drift, carries warm water to the shores of Great Britain and Scandinavia. The *Kuro Shio* is the corresponding current of the Pacific Ocean, but, because it begins in a less-inclosed area and because it spreads more widely over the broad north Pacific, it is not as strongly developed as are the Gulf Stream and the Atlantic Drift.

Because of these currents, the eastern portions of both the Atlantic and the Pacific Oceans, north of latitude 40° N.—but especially the north Atlantic—are decidedly warm for their latitudes. The southern oceans in corresponding latitudes are cold because less warm water flows southward and because the oceans are wide open to polar influences; in the Northern Hemisphere encircling land areas restrict the outflow of cold polar water. The characteristics and effects of these and other ocean drifts and currents will be noted in more detail later under the discussion of the climates of various regions.

Upwelling waters

When coastal surface water is carried seaward, it is replaced by water from greater depths, and the upwelling water is colder than the water that is removed, for warm water is less dense than cold water and tends to remain at the top. The presence of a strong current some distance from the coast often produces an upwelling of water between the main stream and the shore line by carrying some of the surface water with the current. Prevailing winds of moderate or greater velocity blowing from land to sea have the same effect. Upwelling water caused by offshore winds is especially evident in those areas where the trade winds are strong and persistent. Winds approximately parallel to the shore may cause either the withdrawal or the accumulation of inshore water, depending upon the direction of the deflection of the water with reference to the coast. For example, there is upwelling water along the California coast caused by prevailing winds which are almost parallel to the general coastline. The resulting surface drift of water is equatorward, but the water is deflected to the right by the rotation of the earth. Hence, the movement of the surface water is away from the land, and colder water from below rises to replace it. Upwelling water caused at least in part by ocean currents occurs in connection with many of the major cur-

rents, notably the Gulf Stream and the Benguela and Peru Currents. Whatever the cause of the upwelling, the cold water exerts a considerable influence upon the climate of the adjacent coastal regions, as will be noted later in several connections.

Influence of currents on air temperature distribution

The heat capacity of water is great, and the movement of large volumes of water between equatorial and polar regions tends to equalize the temperature of the globe, thus greatly reducing the temperature contrasts that would otherwise exist. The effects supplement those of the similar latitudinal interchange of air. The effects of a warm current are seen in the poleward bending of the isotherms in the north Atlantic (see Fig. 5), and the effects of cool currents are visible in the southward trend of the isotherms of 60° and 70° off the coast of California and in the northward trend of the 70° isotherm off the western coasts of South America and southern Africa. The influence of ocean temperatures upon land temperatures, however, depends upon the transportation of air from the oceans to the land. Northwestern Europe is the warmest land area of the world in its latitude not simply because of the presence of much warm water in the North Atlantic, but because the air that is warmed by passing over the water is carried inland by the prevailing westerlies. Similarly, the west coast of Canada is warmed by the winds from across the Pacific Ocean. In the trade wind belts oceanic influences are carried from east to west, and they affect more directly the eastern sides of continents. Hence, as the combined result of the influence of winds and ocean currents, east coasts of continents are usually warmer in low latitudes than are the west coasts, and west coasts are much warmer in high latitudes than are eastern coasts.

Influence of ocean temperatures on precipitation

Air that moves over warm ocean water becomes highly charged with water vapor. Anything which causes this warm moist air to rise results in condensation and precipitation. The ascent may be due to movement inland over rising ground, to convective instability, or to cyclonic activity; hence, land areas near warm ocean waters usually have relatively high temperature, high humidity, and abundant rainfall, as, for example, the southeastern part of

the United States. On the other hand, the presence of cold water near shore tends to reduce both temperature and rainfall. This is true especially in the cases of upwelling water, because the cold water is near the land and because the temperature contrast between the rising water and the normal temperature of the region is apt to be great. Air moving from the warm water farther out in the ocean is cooled as it moves over the upwelling water, often resulting in dense low fogs; as the air moves inland, however, it is warmed by the normally warmer land surface, the fog is soon dissipated, and the relative humidity becomes low. Coastal regions with cold water along shore are, therefore, often arid or semiarid, with low average humidity but with occasional or frequent morning fogs. Such conditions prevail in Peru and in northern Chile.

Altitude as a Climatic Control

As a result of their altitude and irrespective of latitude or other climatic control, elevated land areas have certain climatic characteristics in common. Some of the distinctive features of mountain and plateau climates will now be noted.

Decrease of pressure with elevation

As we rise above sea level, the air becomes progressively thinner and the pressure decreases with approximate regularity. An average rate often used is 0.1 inch decrease of barometic pressure for each increase of ninety feet in elevation, but the rate of change varies with the actual pressure and with the temperature and humidity of the air, and decreases as we get into the thinner air aloft. A direct result of the decrease of pressure is a decrease in the boiling point of water and an increase in the rate of evaporation at air temperatures. The approximate pressures and the corresponding boiling points are shown in the accompanying table.

Elevation (ft.)	*Pressure (in.)*	*Boiling pt. °F.*
1,000	28.8	210
2,000	27.8	
3,000	26.8	206.5
4,000	25.8	
5,000	24.9	203
6,000	24.0	
10,000	20.7	194

As a direct result, also, of the thinness of the air because of the decreased pressure upon it, there is difficulty in supplying the blood with sufficient oxygen. This results in "mountain sickness," which begins at elevations of 10,000 to 15,000 feet, and which is characterized by dizziness, shortness of breath, weakness, headache, and nosebleed.

Intensity of insolation

The energy of the sun's rays increases with elevation. The increase is rapid in the first 4,000 feet and slow at greater elevations. This is because dust and water vapor intercept much of the solar energy, and are largely concentrated in the lower air. In the thinner, clearer air of elevated regions, insolation reaches the surface with little loss. The air itself, because it has even less absorptive power than in lowlands, is very slightly affected and remains cool, but objects that can absorb radiation are warmed rapidly. Hence, in mountain regions there is a large contrast between the temperature one feels in the shade and that which one feels in the sun. In the Himalayas a thermometer with a blackened bulb exposed to the sun has shown a temperature of 133° when the air temperature was 32°. In mountain regions differences of 40°–50° between the temperatures of objects in the sun and in the shade are not uncommon.

This increased intensity of insolation has an important effect on soil temperatures and the growth of vegetation. The soil becomes warmer than in lowlands with the same air temperature. The solar beam is also richer in ultra violet radiation than at lower levels, and this promotes chemical activity in plants and is also valuable in the treatment of certain diseases of man—tuberculosis and rickets, for example.

Temperature and elevation

As there is rapid heating in the sunshine, so there is rapid cooling by radiation at night in elevated regions, since the air can absorb and return but little radiated heat. This tends to produce large daily and annual ranges of temperature. Great temperature ranges are found to be characteristic of broad plateaus except near the equator, but on mountain slopes this tendency is offset by air drainage and mixing. As the air along a slope cools at night by

conduction of its heat to the land surface, it becomes denser than the air that is some distance from the slope and therefore free from the influence of conduction. The cool air moves downward, but instead of following the hillside closely, as water does, it spreads out from the slope to displace the warmer air. The cooled air collects in mountain valleys and results in temperature inversions, the valley bottoms becoming colder than the mountain sides. Thus are created the "thermal belts" along mountain sides which are more favorable for tender vegetation than are the valley floors. The orange groves of California and the coffee plantations of the Brazilian highlands are placed on slopes to avoid frost damage. The accumulation of cold air in the valleys also often results in fog and clouds in the valleys, especially at night and in early morning, while the sky is clear on the hilltops.

At a sufficient height to be free from direct surface influences, the temperature of the air decreases on the average about 3.2° F. for each 1,000 feet increase in elevation up to heights of a few miles. In the surface air on plateaus and mountains there is also, on the average, a decrease of temperature with increasing elevation above sea-level, but the change is irregular and local. No average value can be given; much depends upon exposure and air drainage. Since there are great local topographical variations of temperature in mountain regions, it is hardly possible to describe all the types of climate existing even within a small area. There are, however, general temperature zones directly related to elevation. High mountains in equatorial regions have all of these zones, beginning with tropical climates and tropical vegetation near the base, gradually changing to temperature conditions and plant species characteristic of middle latitudes, and finally merging into arctic conditions and perpetual snow.

Topography as a Climatic Control

Independently of altitude, as such, there are climatic differences resulting from the configuration of land surfaces. Inequalities in elevation and in the amount and direction of slope cause variations in temperature, wind, cloudiness, and precipitation.

Temperature and exposure

There are great temperature contrasts between the sunny and the shady sides of slopes. A slope facing to the south in the

Northern Hemisphere receives more insolation than would a level surface in the same position, except near the equator, because the rays are more nearly perpendicular to the inclined surface. A northern slope receives very much less heat than a horizontal surface because the rays reach it more obliquely, and do not reach it at all for a considerable portion of the day. Snow remains on northern slopes long after it has disappeared from southern slopes. Eastern sides of mountains are warmed rapidly in the forenoon and western sides in the afternoon, but the duration of sunshine in each case is short as compared with the duration on a level surface.

Winds in mountain regions

Strong winds usually prevail on mountain summits. The velocity is generally greater than in the free air at the same elevation because the slopes tend to convergence of air masses and hence to acceleration of movement. In the lee of mountain ridges and in protected mountain valleys, wind movements are usually light. Plateaus are apt to be windy by day because the rapid heating causes turbulence and mixing, and quiet at night because the cool, dense air tends to remain at the surface. Wind directions in mountainous regions are very local, being much influenced by topography, especially by the trends of ridges and valleys.

Mountains also give rise to certain local winds of a special character which are given distinctive names. A *valley breeze,* which is a movement of warmed air up a valley or up the side of a mountain by day, results from the heating of the valley floor and its slopes by sunshine. *Mountain breezes* occur at night as a result of the rapid cooling of the air near the mountain sides and over sloping plateaus. This cooled air flows down the hillsides and down the valleys. The movement is rather slow ordinarily, but in some cases the air from an extensive upland area converges into narrow valleys and gains considerable velocity.

Winds which result from the flow of cold dense air down slope under the pull of gravity are called *katabatic winds, gravity winds,* or *fallwinds.* Mountain breezes are katabatic winds that are diurnal in character. Over extensive plateaus, cold air may accumulate for several days or more, and then, as a result of changing pressure distribution, it may descend over the adjacent lowlands either by day or by night as cold katabatic winds. Such winds are an occasional and disagreeable feature of the winter climate of the Medi-

terranean coast of France, where they are given the local name of *mistral.* The *bora* is a cold northeast wind of the same character occurring along the northern coast of the Adriatic Sea. Violent katabatic winds, picking up and carrying much snow, and often described as "blizzards," descend from the glacier-covered interiors of Greenland and Antarctica.

Foehn

A wind having special characteristics because it passes over a mountain range is the *foehn,* or, as it is known in the United States, the *chinook.* When the general wind movement forces a mass of air up and over a mountain range, the air cools adiabatically as it ascends, often resulting in condensation and precipitation. The condensation retards the cooling, so that when it descends on the other side after losing some of its moisture, it is warmed more on its descent than it was cooled on the ascent, and it reaches the leeward side both warmer and drier than at corresponding altitudes on the windward side. A foehn, or chinook, is a descending wind which has become relatively warm and dry after moving over a mountain and losing some of its moisture on the windward slope. Such chinooks are sufficiently common in winter at certain places on the eastern slopes of the Rocky Mountains in Montana and Wyoming to cause an appreciable increase in the average winter temperature. They are also frequent on the north side of the Alps in Switzerland.

Precipitation and cloudiness in highland regions

Mountains are very effective in causing or aiding the upward movement of air, and hence, in increasing the amount of precipitation. In general, rainfall increases with elevation up to heights of 3,000–6,000 feet; then it begins to decrease because by that time the air has lost much of its water content. The zone of maximum precipitation is higher in summer, when the air is warm at the beginning of its ascent, than it is in winter. Thunderstorms are frequent in many mountain regions because of the aid to convective instability furnished by the irregular topography. Prolonged steady rains also occur in many mountain regions. These are produced by forced ascent when continuous winds blow against mountain sides. When winds across a mountain range are mostly from

one general direction, the windward side is normally wet, and the leeward side dry.

Broad plateaus usually have light rainfall either because most of the air's moisture is lost before it has risen to the level of the plateau, or because surrounding mountains tend to produce subsidence of air over the plateau. Because of the great temperature contrasts which develop between the heated air near the surface of the plateau and the free air not affected by surface heating, however, plateaus are subject to intense thunderstorms and hailstorms. Nevertheless there is generally little cloudiness and much sunshine in plateau areas.

Snow line

Many high mountains are permanently covered with snow. The lower limit of a perpetual snow cover is called the *snow line*. The elevation of the snow line depends chiefly upon the average temperature, but it depends also to a considerable degree upon the temperature range and upon the total annual snowfall. Where the annual range of temperature is great, the warm summers cause the snow line to retreat, no matter how cold the winters. The amount of precipitation is important, because less heat is required to remove a shallow covering of snow than a deep cover. The amount of snowfall is sometimes the controlling factor. For example, in the Himalayas the snow line is lower on the warm southern side which has a very heavy snowfall than on the much colder northern side where the precipitation is lighter.

Mountains as barriers

Not only do mountains have characteristic climates due to their elevation, but mountain ranges influence the climates of great areas on either side of them. Mountains modify the air which passes over them and they deflect the air currents; this often results in marked differences of climate in the regions which mountains separate. Mountain systems serve as divides between climatic regions in somewhat the same way as they divide the drainage areas. The east-west trend of the Alps protects northern Italy from many of the storms and much of the cold weather of central Europe. The north-south trend of the Rocky Mountains permits cold air from Canada to extend southward to the Gulf

coast. The Andes separate the wet marine climate of southern Chile from the continental desert climate of southern Argentina. A similar sharp contrast between the western portions of Oregon and Washington and their eastern portions is due to the mountain barriers that cross these states.

Temperature Controls

The charts of temperature distribution for the year and for June and July (Figs. 5, 6, and 7) show first the latitudinal effect as modified by continental and marine influences. The continental influence is shown in the January chart by the presence of the coldest regions over large land masses of the Northern Hemisphere (Siberia, northern Canada, and Greenland) and of the warmest regions over the land masses of the Southern Hemisphere. The latter are not at the equator but near the Tropic. This is an insolation effect, for the sun is vertical at the Tropic of Capricorn in January, and the days are longer there than at the equator. Similarly, in the July chart the hottest regions are over land areas near the Tropic of Cancer, in the Sahara and southwestern United States, but because there are no large land masses south of the Tropic in the Southern Hemisphere (omitting Antarctica from consideration), no cold areas are developed. South of latitude 40° S., the isotherms run nearly parallel, east and west, and temperatures are not nearly so low as in corresponding latitudes of the Northern Hemisphere in winter; the moderating and equalizing effect of uninterrupted ocean areas is thus manifested. Seasonal effects of changes in insolation are shown by the northward migration of the isotherm of 70° in the Northern Hemisphere from January to July. Over North America this isotherm moves from central Mexico, latitude 20° N., to southern Canada, latitude 50° N., and over Asia it migrates 35° of latitude northward, from Indo-China and central India to Siberia.

The warm air overlying the warm waters of the Atlantic drift and the Japan current is carried to the western coasts of Europe and North America by the prevailing westerlies, and the marine influence is shown in the tendency of the isotherms to follow the coast lines (see the January isotherms of 20°, 30°, and 40° on the west coasts of both continents). The north-south trend of the January isotherms over Europe indicates the great extension of the

marine influence inland because of the absence of intercepting mountain ranges and the irregularity of the coast line. The marine influence is much less extensive in the Americas because of the western mountain systems. The prevailing westerlies carry continental influences to the east coasts of North America and Eurasia, and these coasts are therefore colder in winter and warmer in summer than are the western coasts in the same latitude.

Mean annual ranges (Fig. 9) illustrate clearly the two predominating temperature controls: (a) latitudinal effect due to increased seasonal changes in insolation from equator to poles, and (b) the differences between land and water surfaces. The great seasonal changes between winter and summer are over large land masses; even in high latitudes ranges are mostly small over the oceans. In tropical oceans the range is less than 5°; in the Sahara, a continental desert partly within the tropics, the range is six times as great.

The map of actual mean annual temperatures in the United States (Fig. 20) shows some of the effects of elevation. The map is based on the normal temperatures of 158 Weather Bureau stations, and hence, does not show actual mountain conditions, but rather, the conditions in the valleys and plateaus where the cities are situated. The decrease of temperature with elevation is indicated, however. Also the role of mountain systems as barriers is shown in the north-south trend of the isotherms in the western portion of the country, particularly the extent to which these lines bend southward on the eastern slopes of both the Rocky Mountains and the Sierra Nevada.

A comparison of the normal, annual temperature with the average annual number of degree-days of heating illustrates some climatic differences. Fig. 21[1] is based on the same data as is Fig. 20. Although the general distribution of degree-days and annual temperatures is similar, there are striking differences in detail, particularly between the Pacific coast and the interior of the continent. Wichita and San Francisco have the same mean annual temperature, but the former has a 40% greater number of degree days. Los Angeles has about the same temperature as Little Rock, but about half the heating load.

[1] A. G. Topil, "Degree-Day Normals over the United States," *Monthly Weather Review,* Vol. 65 (July, 1937), pp. 266–268.

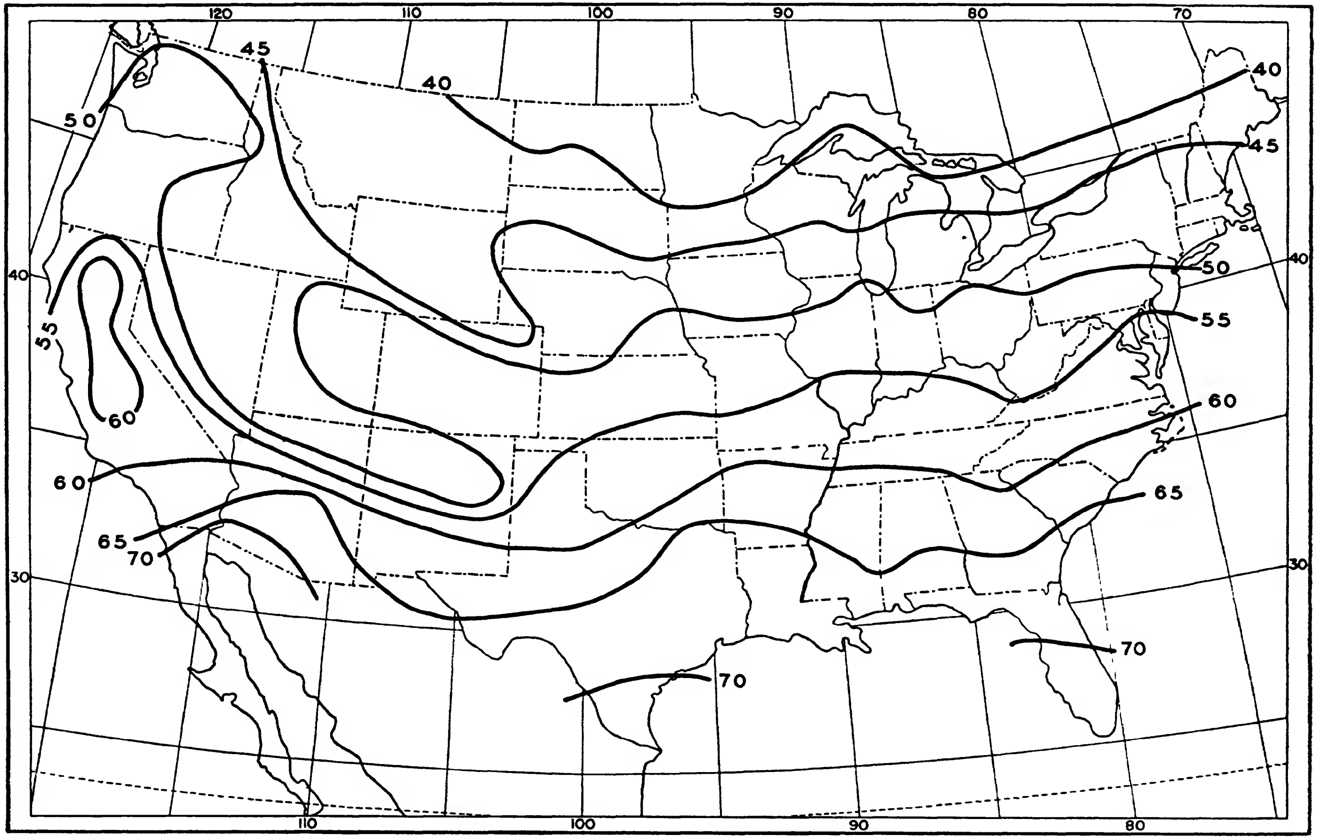

Fig. 20—Normal Annual Actual Temperatures, United States, °F.

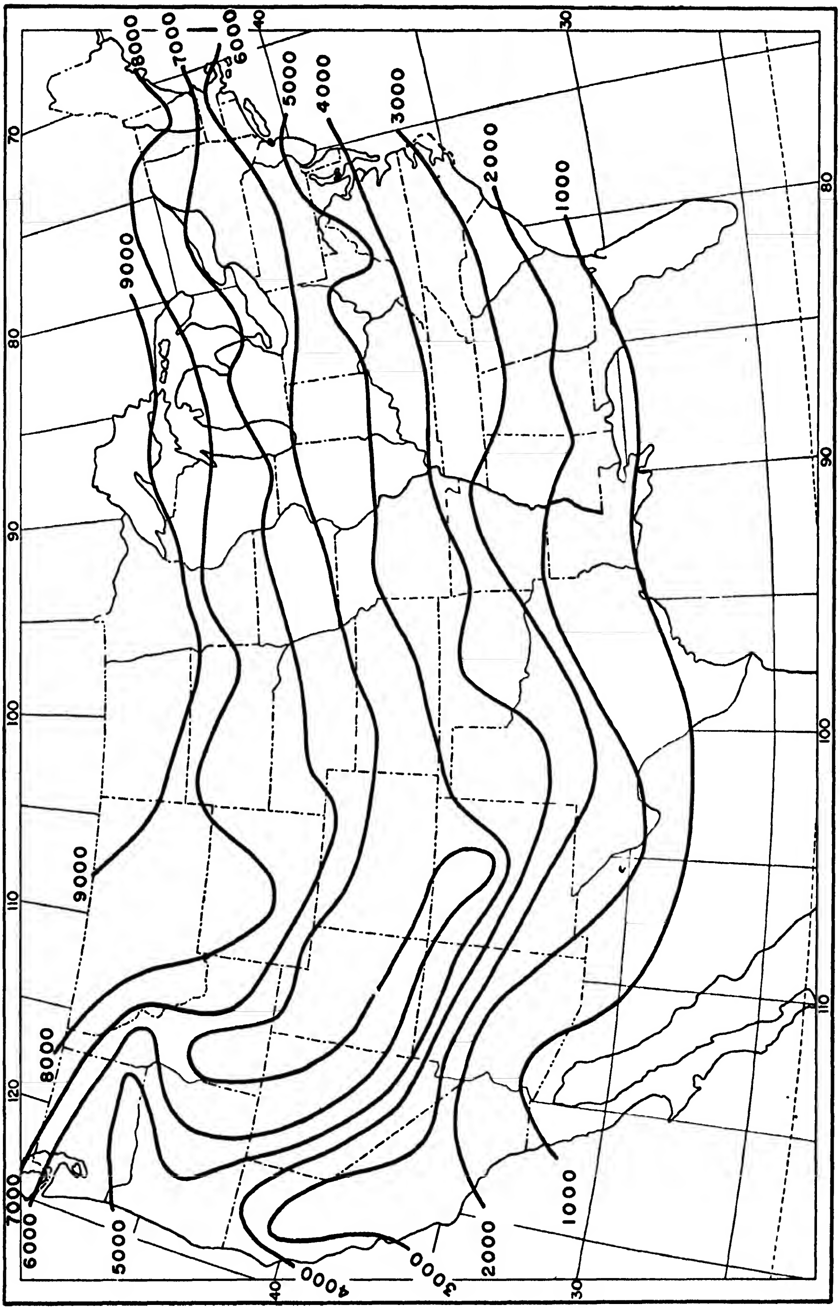

FIG. 21—Average Annual Number of Degree-days of Heating, United States, °F.

Precipitation Controls

Some of the factors influencing annual rainfall amounts may be detected by comparing a map of mean annual precipitation (Fig. 8) with maps of mean pressure and prevailing winds. The following facts about the general distribution will be noted:

Very heavy rainfall

Very heavy rainfall (more than eighty inches) is confined to the following general regions:

(a) Portions of the doldrums—the Amazon Valley, west Africa, and the Netherlands Indies. The rainfall is of the convectional thunderstorm type, produced by quiet, hot, moist, rising air.

(b) The southern slope of the Himalayas—orographic rain, produced by the up-slope movement of the warm, moist southwest monsoons; the Malay Peninsula and the Philippines are also under the influence of the monsoons.

(c) Windward slopes of mountains in the trade wind belts—Madagascar in the southeast trades, Guiana in the northeast trades, and small areas in the Hawaiian Islands; the controls are again mountains and prevailing winds.

(d) Small areas along the west coast of North America from Oregon to southern Alaska where the prevailing westerlies blow against mountain ranges.

In all cases, except in equatorial regions, very heavy rainfall is orographic in origin.

Heavy rainfall

Amounts of forty to eighty inches occur in the following situations:

(a) In transitional zones around the areas of very heavy precipitation just mentioned. The most extensive of these zones are in tropical Africa and South America (under the influence of the doldrums in their seasonal migrations), and in Burma, Siam, and French Indo-China (under the influence of the monsoons).

(b) In the southeast United States and in southwest China, where southerly winds prevail in summer and bring to the land air that has been warmed and humidified over tropical ocean areas. In winter, traveling cyclones move over these regions and are fed

by air from the same source. The rainfall is both cyclonic and convectional.

(c) In the prevailing westerlies in small areas on the west coasts of Europe and North America, the southwest tip of South America, the southern end of Greenland, and in New Zealand; the rainfall is mainly due to the frequent cyclonic storms of the westerlies.

(d) In north and east Australia, where the trade winds blow against rising ground.

Moderate and light rainfall

Areas receiving twenty to forty inches annually usually border the regions of heavy rainfall toward the interior of continents, but they extend to the eastern coasts in middle latitudes of North America and Asia. Regions of moderate rainfall shade into regions of less than twenty inches in the interiors of continents and in high latitudes as the distance from warm water surfaces increases. The effect of mountain barriers is seen in the light rainfall of Sweden and of the Great Plains of the United States. The belt of moderate rainfall is narrow on the western coast of North America because of the intercepting mountains, and extensive in Europe because of the absence of such barriers. Belts of moderate and then light rainfall also border the tropical areas of heavy precipitation in latitudes receding from the influence of the doldrums and approaching the trade winds.

Scanty rainfall

Amounts of less than ten inches occur:

(a) In the flat trade-wind deserts of Sahara, Arabia, and Australia, and in smaller areas in the trade-wind belts on the western sides of South America and southern Africa. These latter areas are also influenced by down-slope air movement and by cold ocean water close inshore.

(b) In the interior of continents in the subtropical high pressure belts, especially in inclosed basins. These dry areas have their greatest extent in Mongolia and southwestern Siberia (the Gobi and Kara Kum deserts of inner Asia), but they are extensive also in the southern plateau region of the United States and in southern Argentina.

(c) In Polar regions where the air is continuously too cold to contain much water vapor.

Summary

The amount of solar heat entering the atmosphere at any place on the earth's surface is determined by astronomical factors, and can be calculated from the solar constant and the latitude of the place. But winds, ocean currents, land distribution and elevation, and many other geographical factors interact to redistribute the sun's energy. Hence, the actual climate is the result of a very complicated play of influences, and can be described with accuracy only on the basis of a long series of weather records.

Consider, for example, the climate of St. Louis, Missouri. Its latitude (38° 38′ N.) determines the possible amount of insolation —somewhat less than fifteen hours of sunshine per day in midsummer, and somewhat more than nine hours in midwinter. Its position in the interior of the continent in connection with its latitude gives it a rather large mean annual range of temperature—from a July mean of 78.8° to a January mean of 31.1°. The temperatures and the temperature ranges are also influenced by the fact that the prevailing winds are southerly during the summer and northerly in winter, and that there are no mountain ranges to interfere with the free movement of tropical maritime air from the south or polar continental air from the north. By their north-south trend, the Rocky Mountains influence the flow of the cold air southward. Thus, the presence or absence of mountains, the configuration of the continent with large land masses in high latitudes, and the presence of a large supply of warm water in the Gulf of Mexico all modify the temperature of St. Louis. Its lower elevation and its greater humidity give St. Louis a smaller daily range of temperature than is found in the Plains region farther west.

St. Louis' moderately heavy annual rainfall (37.44 inches) is due to the fact that it is open to the supply of warm moist air from the Gulf, and that it is also in the path of many cyclonic disturbances moving from the southwest and bringing this moist air with them. Its annual rainfall is nearly twice that of western Kansas in the same latitude, which is in the shadow of the Rocky Mountains and which is much less frequently in the path of Gulf air. The presence of a large supply of warm water in the Gulf and

Caribbean region is due to the Equatorial Current, the trade winds, and the configuration of the coasts of North and South America as far south as Cape St. Roque.

Thus in the climate of any locality we may trace the effects of latitude, altitude, position relative to land and water areas, mountain ranges, and storm tracks, and also the influence of ocean currents and the general atmospheric circulation. H. R. Mill has expressed the relationship thus: "The whole world is knit together, every part of it affecting every other. Configuration redistributes solar heat and makes our climate; climate rules supreme over plant life and animal life; and all, together, conspire to render certain parts of the world pleasant, tolerable, or deplorable as the abode of man." [2] The redistribution of solar heat is made by ocean currents and by winds—about equally by each, it has been estimated. The temperature and moisture of the moving air at any place largely depend upon the previous history of the air and upon the influences to which it has been subjected as it has moved over warm or cold, land or water, surfaces. Hence the wind that is blowing at the time largely governs the weather at a given time and place, and the prevailing winds largely determine the climate.

[2] H. R. Mill, "Climate and the Effects of Climate," *Quarterly Journal Royal Meteorological Society*, Vol. 27 (July, 1901), 169–184.

CHAPTER VI

Climatic Variability

In the preceding chapters climate has been discussed as if it were a definite and invariable condition controlled by fixed and unchanging influences, and as if the climatic elements of a given region had "normal" values which could be expressed with numerical exactness by averaging weather data for fifty or 100 years. Such, however, is not the nature of climate. Superimposed on a large scale stability and permanence, there are numerous climatic fluctuations of varying intensity and varying period.

Geological Changes of Climate

Geological records give evidence of several great glacial periods, when moving ice-sheets such as now exist in Greenland and Antarctica covered large portions of northern Europe and North America. Excluding minor episodes, five glacial epochs are recognized in the United States. In the United States glaciers at one time extended southward into Missouri, Illinois, Indiana, and Ohio. In Europe they covered Great Britain, and moved south from Scandinavia into Germany and Poland. The development of these great ice sheets was not uniform and continuous, but was marked by advance and retreat, warmer (or drier) periods intervening between the cold periods. The latest great glacial age began perhaps a million years ago (or perhaps a half million), but the last great ice sheet disappeared from North America only about 25,000–50,000 years ago.

The glacial epochs were short, geologically speaking, for between them there were much longer periods of relatively genial climate. During these mild periods the great coal beds of Great Britain and the United States were formed from dense tropical forests, or from conditions somewhat similar to those that now prevail in the Everglades of Florida. Poplars, elms, and willows

grew in Ellesmere Island at latitude 80° N., where now only lichens and mosses survive. Alaska, Greenland, and Spitzbergen once had a plant life that is indicative of a mild, temperate climate. Thus, the evidence of geology is that many and important climatic changes have occurred in the history of the earth. The conclusion of most geologists is that, although these changes were irregular and fluctuating in character, they occurred simultaneously over the whole earth.

Secular Trends

In addition to the large climatic pulsations, marked by glacial and interglacial epochs, in periods of millions of years, there are various evidences of many lesser variations in climatic conditions, not necessarily world-wide in their incidence. Since the disappearance of the glaciers from the continents of Europe and America (except in high mountains), peat bogs in which are preserved many plant seeds and spores have formed. A study of the distribution of these plant remains has led to the conclusion that there have been climatic trends approximately 1,000 or 2,000 years in length—periods of perhaps 1,000 relatively dry years followed by 1,000 wet years.

Great Salt Lake is the remnant of a very much larger lake, Lake Bonneville, which once covered western Utah and part of Idaho and Nevada. The former shore-lines of the lake are well marked by terraces and water-cut cliffs. These, together with dry alluvial deposits at two levels, make it possible to decipher the climatic history of the region. First, a dry basin was occupied by a small shallow lake; then a long period of wet weather (and perhaps cold, also) caused the lake to rise and spread until it became as large as Lake Huron and 1,000 feet deep. Subsequently there was a long dry period during which the lake disappeared entirely. This was followed by a rapid rise to somewhat greater size than before, indicating a very wet period, which however did not last as long as the first wet period, and which was followed by the present dry era during which the lake has receded and has left only shallow bodies of salt water.

The fluctuations of lake levels in other parts of the world, and the retreat and advance of Alpine glaciers tell a similar story. The sequoias of the western coast of North America often live to

be more than 1,000 years old and some of about 3,000 years are known. A study of their growth rings has revealed fluctuations in their rate of growth, evidently because of climatic variability. These rings show alternating trends in periods of a few hundred years, and within these longer cycles there are short-period fluctuations. Dates of grape harvests in France from the fourteenth century to the present point toward oscillations of a week or two in the time of ripening from century to century, but indicate no progressive change in either direction.

Evidences of secular trends in climate are also to be found in actual instrumental records in some parts of the world. There are temperature records of 100–150 years at a few places in eastern United States and in Great Britain and northern Europe, and these in most cases show a trend toward warmer weather beginning about 1860 or 1870 and continuing in some cases to the present time. A study of temperature records in the British Isles, comparing the period from 1851 to 1900 with that of 1901 to 1930, shows that the latter period has been appreciably more "oceanic," with higher winter temperatures and smaller annual ranges of temperature. These temperature changes appear to be in general accordance with accompanying changes in pressure distribution and winds.

Weather Cycles

Coming to a consideration of still briefer time intervals, we find climate showing the same oscillating nature. Bruckner, using data on the changing level of the Caspian Sea and the changing front of Alpine glaciers, covering the years from 1020 to 1890, found evidence of a weather cycle averaging about thirty-five years in length, during which a series of cool and wet years alternated with a series of warm and dry years. Other evidences of this "cycle" have since been found in other parts of the world, in some cases indicating a variation of about 20% in precipitation. There is probably some real fluctuation represented by these findings; but the variations are not truly cyclical, for the length of individual "cycles" varies from twenty to fifty years. There are also frequent local exceptions and temporary reversals of trend. Hence, the record is of little value as an indicator of future conditions.

Similarly, many weather records and the records of tree rings and glacier deposits give indications of periodic changes in climate about eleven years in length; these changes are presumably related to the cyclical changes in the number of sunspots which have a period averaging about eleven years. The Bruckner cycle and the sunspot cycle are the two best known and most nearly proved

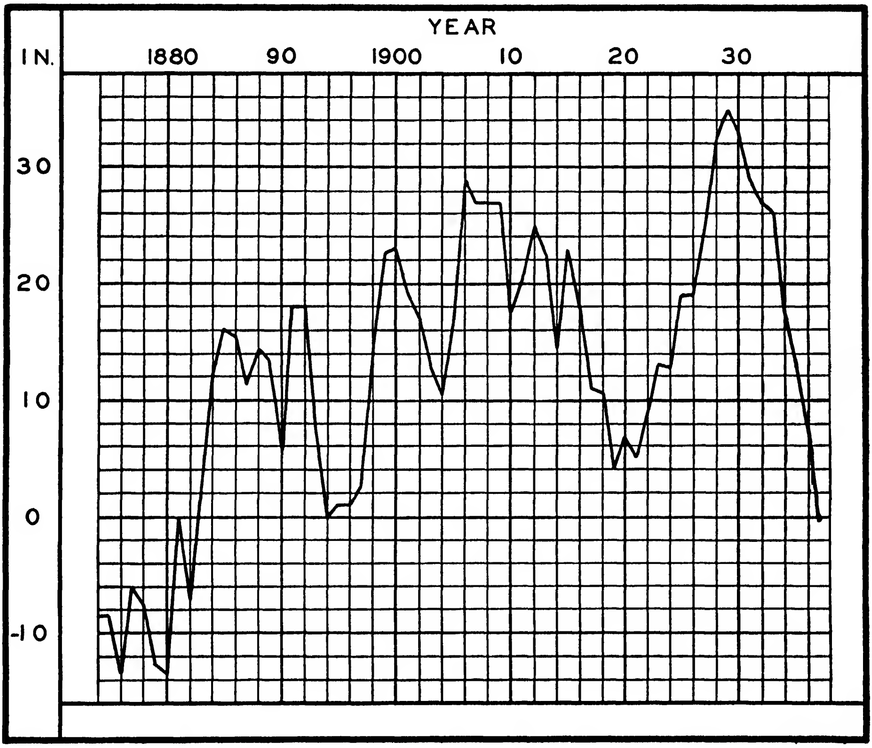

Fig. 22—Accumulated Sums of Departures, Annual Precipitation, Dodge City, Kansas.

weather periodicities, but mathematical analysis of records has disclosed more than 100 so-called "cycles," varying in length from eight months to 260 years. Many of these apply only to single records or to small areas of the earth; none of them recurs with precise regularity as to time or amplitude, and most of them are subject to sudden unexplained interruptions or changes of phase. The net result is that, considered all together, they have little significance in indicating the future course of climatic changes.

These short period oscillations are significant in two respects, however. In the first place, they serve to complete the picture of the essentially pulsating nature of climate. Climatic conditions neither remain constant nor change forever in one direction, but instead they vibrate back and forth in a highly complex and irregular manner in waves of lengths varying from a few months to millions of years.

In the second place, the changes of a few years' duration are often of great social and economic significance to the people who experience them. This is especially true of variations in rainfall in regions where the "normal" amount is barely sufficient to sustain agriculture, and it is in such regions that the percentage variation between wet periods and dry periods is often greatest. In a series of wet years such regions produce good crops and support a considerable population; in a series of dry years there are crop failures, abandonment of land, and reduction of population; property becomes unsalable. The nature of such weather cycles is indicated in Fig. 22, in which the variation in annual rainfall at Dodge City, Kansas, is shown by plotting the accumulated algebraic sums of the departures from the average for the entire record. Years in which the curve moves downward were years of light rainfall; those in which it moves upward were wetter than average. This curve gives clear evidence of the existence of alternating wet and dry periods, which, however, are of unequal length. The longest wet period comprised the eight years from 1922–1929, inclusive, and the longest dry period was that beginning in 1930.

Suggested Causes of Climatic Variability

Why does climate show these fluctuations in long and short, but unequal, periods? Why is there always a return from one extreme to the other? These questions have received much careful consideration and have given rise to many theories, but as yet there has been no complete and satisfactory answer. Since the longer changes were simultaneous over the whole earth, in considering possible causes we must inquire what are the large general physical factors controlling the climate of the entire earth as distinguished from the more localized terrestrial controls discussed in the preceding chapter. These larger influences will now be noted briefly.

Solar constant

Other things being equal, it is evident that the amount of heat received by the earth varies with the amount emitted by the sun, that earth temperatures depend primarily on solar activity, and that large changes in solar output, if they occur, will be reflected in climatic changes on the earth. Slight changes in the solar constant are indicated by modern measurements. No evidence exists of marked differences in past ages, but such may have occurred, for in the nature of the case there can be no direct evidence on this point. The causal connection of the known solar changes of short period with weather and climatic fluctuations has not been proved. The occurrence of larger variations in past ages and their relation to the ice ages are wholly speculative.

The "solar cyclonic hypothesis" presents a theory that changes in solar activity cause a redistribution of the earth's atmospheric pressure and a shifting of the wind belts and storm tracks. The argument is that a change of, say, 10% in the solar output would cause a greater actual change in the amount of heat received where the total insolation is great, as in equatorial regions, than where it is small, as in polar regions. This would result in different temperature contrasts between high and low latitudes, causing changes in the position of pressure belts, wind systems, and paths of cyclones and anticyclones.

Such a redistribution of pressure would result in different responses in different parts of the world; one region would be wetter and another drier, or one warmer and another colder. This theory is therefore used, not to explain the larger fluctuations of the geological past, but the fluctuations of short periods. Solar radiation is affected by the number and area of sunspots, and there is considerable evidence of a relation between weather cycles and sunspot cycles. But this theory of the control of weather by changing solar output is, in itself, inadequate to explain all the observed weather relations and short-period climatic fluctuations.

Earth movements

The earth moves about the sun in an orbit that is almost but not quite circular. The orbit is slightly elliptical, the sun being a little off center. The amount of this eccentricity varies slightly in a period averaging about 100,000 years, and also changes some-

what more through longer periods of time. An increase of the eccentricity over its existing value means a flattening of the ellipse, bringing the earth nearer the sun during half of each year and farther from the sun during the other half. Meanwhile, two other changes are taking place: (a) at present winter occurs in the northern hemisphere when the earth is nearest the sun (perihelion), because the North Pole is then pointed away from the sun; the perihelion phase undergoes a slow change, making a complete circuit in about 21,000 years and changing the relative amounts of insolation received at different seasons, and also in the Northern and Southern Hemispheres; (b) a slight change in the angle which the earth's axis makes with the plane of its orbit (obliquity of the ecliptic) occurs very slowly; increased obliquity results in increased insolation in polar regions as compared with equatorial regions.

Through geologic ages these three factors may combine in various ways to produce considerable changes in the relative amounts of insolation received in different parts of the earth and at different seasons of the year. It is doubtless true that they have had a considerable effect upon the slow cyclical changes of climates through the long periods of geologic time. On the other hand, a careful analysis of the possible physical effects of these changes, and a comparison of the time elements with those of accepted geological history, have led most students to the conclusion that such changes do not offer a satisfactory explanation of the ice ages and of the long warm intervals between the glacial epochs.

Composition of the atmosphere

Changes in the composition of the air might result in important changes in the absorption of incoming and outgoing radiation. Increased absorption of insolation would result in a decreased amount of heat received at the earth's surface, and increased absorption of outgoing earth radiation would result in increased temperatures in the lower air.

Although the gaseous constituents of the air seem to be practically constant, there may have been changes in past geological periods. In particular, one theory of glacial climates assumes important changes in the amounts of carbon dioxide (CO_2) in the air. This gas is a better absorber of earth radiation than of solar radi-

ation. The assumption of the theory is that the earth will be warm when the air contains large amounts of CO_2 and cold when the amount is considerably reduced. It has been shown, however, that with a moderate amount of it, as at present, doubling the amount would not materially increase the absorption of earth radiation, and it has been further shown that water vapor in the air acts in the same way as CO_2 and on the same wave lengths. Apparently the only way in which changes in CO_2 could materially affect the climate of the world would be by affecting the upper air above the water vapor; it is doubtful whether this was an important factor in glaciation.

Another possible change in the composition of the air is in its dust content, especially in relation to volcanic activity. Volcanoes frequently throw great quantities of fine dust high in the air, and Humphreys has shown that the effect of such dust in the stratosphere is to cause a lowering of the surface temperature. The effect is due to the reflection and scattering of the short-wave solar radiation, rather than its absorption, while long-wave earth radiation is permitted to escape. Because of the greater angle of incidence, the scattering of insolation would be greater in high latitudes than in the Tropics. This would increase the temperature differences between polar and equatorial regions, quicken the air circulation, and increase precipitation. Heavy precipitation is favorable to the formation of glaciers, and once started, glaciers contribute to their own growth by reducing the air temperature. Although there is no direct evidence of the extent of this influence, it seems probable that periods of great volcanic activity may have contributed to extensive glaciation.

Land distribution and elevation

The effects of large land and water areas on climate have been noted previously. It is evident that changes in the ratio of land area to water area would result in climatic modifications; the extent and distribution of continental and marine climates would be altered. Since large land masses average warmer than water areas in low latitudes, and colder in high latitudes, increasing the extent of tropical land masses would increase the mean temperature of the world; on the other hand, enlarging the land areas in high latitudes would reduce the mean temperature, and might result in

glaciation. Such changes would also modify the circulation of the air. Centers of high and low pressure would be altered in position and intensity, and the monsoons would be rearranged; the source regions of polar and tropical air masses would be shifted, and with them the tracks of cyclones and anticyclones.

Elevation also has an important effect on temperature; mountains and plateaus are colder than lowlands. It is probable that a general increase in elevation would accompany any large increase in land area. If these changes took place poleward of latitude 40°, the two influences would combine to reduce the temperature of the world. If, for example, the great plain of Russia and Siberia, now of moderate elevation, were raised a few thousand feet and became a high plateau, much of it might well be covered with glaciers. The cooling of the air by such a large ice sheet and the drainage of the cold air into lower levels would reduce the mean temperature of the globe, and might result in the extension of glaciers into lower lands farther south.

Moreover, changes in land area and distribution would result in changes in oceanic circulation, and hence in the equalizing effects produced by ocean currents. If a large polar ocean were entirely surrounded by land, thus preventing the interchange of warm and cold water, the polar area would become progressively colder, for radiation losses in high latitudes are greater than radiation gains. Humphreys believes that a land connection between Greenland, Iceland, the Faroe Islands, and Scotland, thus shutting off the northeast Atlantic from the warm waters of the Atlantic Drift, and probably causing a shift of the Icelandic low pressure area far to the west, would give Norway and Sweden a climate and an icecap like those of Greenland today, and lead to the glaciation of other portions of northern Europe. Similarly, closing the gap between South America and Antarctica, or opening a gap across Central America, would lead to changes in oceanic circulation and resulting modifications of the climates of large areas.

Geologists believe that there have been in the history of the earth certain periods of intense activity in land elevation and mountain building, and that these periods were rather short as compared with the long intervening periods of comparative inactivity, during which the slow processes of erosion gradually reduced the elevation of the mountains and plateaus. This work of

sculpturing the landscape anew proceeds with "infinite deliberation." There is evidence that the great glacial ages have coincided with or closely followed the periods of mountain-building activity, and that the long warm intervals between the ice ages have occurred with the periods of structural inactivity in the earth's crust.

Summary

These four factors—solar radiation, earth movements, composition of atmosphere, and distribution and elevation of land—govern the general climate of the world as it is, and presumably have governed the climates of the past. All four factors may have been influential in the pulsatory changes of past ages, but when examined in detail, they do not offer a satisfactory explanation of the actual climatic changes indicated by accepted geological evidence.

The one factor whose influence is best known and which comes nearest to accounting for the known variations of the larger kind is the one having to do with the changing surface features of the earth and the accompanying variations in the amount of volcanic dust in the atmosphere. Huntington and Visher state that "There is no question that height and extent of continents, location, size and orientation of mountain ranges; opening and closing of ocean gateways and consequent diversion of ocean currents exert a profound effect on climate," and Brooks in his *Climate Through the Ages* has presented much evidence that such changes are sufficient to cause severe glacial and mild interglacial epochs.

Nature of Climate

The extensive study that has been given to these large factors controlling the climates of the earth has not served to explain past and present climates fully, but it has served to define the nature of climate. Two fundamental facts about the nature of climate are now evident:

(a) Considered in relation to the possible changes, the climate of the earth has been remarkably stable for millions of years. Water and life have existed on this planet for long ages, which they could not have done if temperatures had been markedly higher or lower than at present.

(b) Superimposed on this large stability is a marked variability

of the nature of waves, i. e., of fluctuations back and forth about a mean. The waves vary in length from those of the glacial and interglacial eras, millions of years in length, to the short " cycles " of a few years or even of a few months. The shorter waves may be due to variable amounts of insolation, to changes in temperature of land and water surfaces, or to natural periods of vibration of the atmosphere.

Definition of climate

It is now evident that the ordinary definition of *climate* as an integration of weather conditions over a considerable period is insufficient. We must designate more definitely the time scale in which we are thinking. In terms of geological epochs, the climate is always changing. In terms of hundreds of years, there are secular trends of more or less significance. In terms of decades, there are warm and cold periods, dry and wet periods.

How, then, shall we define *climate?* In discussing the climates of the earth in their geographical aspects as a part of the environment of man of the present day and of the historical past, we may evidently disregard the slow changes occurring in geological periods. On the other hand, the fluctuations of short duration are evidently to be regarded as characteristic behavior and not as climatic changes. *Climate* may then be defined as *the summation of weather conditions in historical times.* As we have seen, there are evidences in some parts of the world of considerable changes within the historical period, but apparently we may regard all such variations as nothing more than fluctuations of longer or shorter periods, and not as permanent changes in one direction.

Unfortunately, we are not able to use as short a period as the past few thousand years to determine (except in very general terms) the climate of a region. There are accurate and comparable records of the climatic elements only during the past 100 or 200 years. Actual climatic " normals " in use today rest upon records of less than 100 years, often of only twenty years. A period of thirty-five years, representing the average length of the Bruckner cycle, is often used where available, and yields a fairly stable mean value.

None of the longer climatic controls discussed in this chapter changes suddenly, and none is subject in the least to man's influ-

ence. We can say with confidence that climate in the sense just stated does not change abruptly or perceptibly in the life of an individual, and that it is not influenced by the activities of man except locally and transiently. Climate can be depended upon to be much the same in the next 100 years as in the past 100 years. It is relatively stable in a world in which many other elements of man's environment are changing rapidly. The weather returns "in its season from year to year" without lasting change, but with constant variability. These minor fluctuations are often important to man and the use he makes of the earth's surface.

CHAPTER VII

Climatic Influences

The influences exerted by climate upon the surface of the earth and upon the plant and animal life inhabiting the earth are so numerous and all-pervading, and often so subtle, as to defy complete identification and analysis. Man's "housing, clothing, food, occupation, migrations, various forms of government, and manner of living are all more or less influenced by the climate in which he dwells."

Climatic hypothesis

A consideration of the varied and intricate responses of man to his physical environment has led some geographers to a theory of "environmental determinism," by which an attempt is made to explain the entire form and content of the culture of a group in terms of geographical influences. As a part of this doctrine of determinism, and with specific reference to climate as a major part of the environment, the "climatic hypothesis of civilization" assumes that climate has been the one major and essential factor in the development of civilization, and that physical and mental energy and moral character reach their highest development only in those limited regions where the climate is peculiarly favorable. Such an hypothesis assumes very literally that "We are what suns and winds and waters make us," and either neglects or minimizes the effects of heredity, religious philosophy, and human personality. It assumes that man's reactions are fixed and mechanical. It does not sufficiently consider the extent to which man has overcome and modified the disadvantages and limitations of his natural surroundings, or the historical fact that progressive civilizations have grown up in many climates, ranging from the subtropical desert of the Nile valley to the subarctic highlands of Sweden.

The importance of climate in the affairs of man cannot be doubted. It will be the purpose of this chapter to indicate briefly some of the ways in which climatic influences are exerted and

some of the effects produced "where life gives battle to the elements." These effects are of sufficient consequence and significance to deserve careful consideration in themselves without resort to any theory of compulsion. We can safely say that the cultures of the various groups of mankind result from many factors, and that among the physical factors involved none is more potent than climate.

Climate and Soils

The surface of the land is everywhere and at all times modified by the process of *weathering*—meaning the disintegration of the solid rock into finer material and its chemical decomposition into other compounds. The use of the word *weathering* in this connection is a recognition of the importance of weather and climate in transforming the surface of the earth. Climate directly influences soil formation in several ways. Insolation heats the rock surfaces by day, and radiation cools them by night. This results in unequal expansion and a cracking of the rocks. This type of weathering, depending solely on large ranges in temperature between day and night, is active in deserts. Water falling as rain or snow enters the crevices thus formed, and when this water freezes it expands and causes further breaking up of the rock material. Weathering of this kind proceeds most rapidly, therefore, where rainfall is frequent and abundant, and where there are frequent changes of temperature above and below freezing. Water and high temperatures promote chemical activity, and weathering by chemical decomposition is therefore most active in the warm and moist tropics; it decreases in general, with increase of latitude. The speed of chemical reactions approximately doubles for each rise of 18° F. in temperature.

Water plays another important role in determining the composition of soils. In wet regions, where precipitation exceeds evaporation, water percolates through the soil to a permanent water table, and in doing so carries much of the soluble material from the soil. This process is known as *leaching*. Leaching leaves the soil deficient in lime, but oversupplied with iron and aluminum compounds, and with a more or less acid reaction. Where rainfall is less than evaporation, the soluble materials are not leached out, and the soils are generally rich in lime. The freezing of the

soil prevents percolation and slows these processes, as for instance in the frozen plains of northern Canada and northern Asia. This relation of climate to soil composition is the basis of the division of the soils of the earth into two major groups: *pedalfers*, "iron" soils, and *pedocals*, "lime" soils. In the further classification of soils by the subdivision of these two groups, it is found that soil belts largely coincide with climatic belts, and soil scientists now recognize that "climatic forces are the predominant soil-forming agencies of the world."

Climate and Land Forms

The general process of the wearing away of the earth's surface by natural agencies is called *erosion*. Several climatic elements are important in erosion. Water falling as heavy rain on sloping ground accumulates in rivulets and small streams, and finally in rivers, and in doing so transports loose materials, wears down mountains, dissects plateaus, forms ravines, valleys, hilly lands, and plains, removes soil from large areas, and makes deep alluvial deposits in other regions. This type of erosion is directly related to the intensity of the rainfall (among several factors). One reason for the fact that there is less erosion in England and France than in much of the United States is the gentle character of most of the rainfall in the former countries. Erosion is also related to total rainfall, as is shown by the fact that the land forms found in arid and semiarid regions differ from those in humid climates. Thus, both the amount and the intensity of rainfall are important in modifying the forms of the land.

Glaciers too have left distinctive land forms easily recognized by geologists. Glaciers smoothed and rounded the hills, dumped loose material into the valleys, and built up terminal hills and ridges along their margins. The third climatic factor of importance in altering the forms of the land is wind. In deserts and semi-arid regions, wind picks up the particles of sand and uses them to wear away exposed surfaces, or moves them along the surface to form stationary or drifting sand dunes. In certain areas fine, wind-blown particles have accumulated to form a deep, rich soil material known as *loess*. Thus, climate is important in the removal and rearrangement of that mantle of loose material at the surface of the earth which is itself the product of weathering.

Climate and Natural Vegetation

The chief factors in the distribution of native vegetation are soil and climate. Soils, however, are largely determined by climate, and hence climate is the one most important and most fundamental control. The chief elements of climate governing the distribution of plants are temperature and precipitation. On the basis of moisture alone the native vegetation of the earth falls into three great groups: (1) forests, requiring in general abundant rainfall; (2) grasses, prevailing in regions of moderate to light rainfall; and (3) desert vegetation (xerophytes) existing under conditions of scanty rainfall.

On the basis of temperature there are: (1) the tropical plants (megatherms) requiring continuous high temperatures and abundant moisture; (2) the great variety of plants of the lower middle latitudes (mesotherms) requiring considerable heat, but tolerant of short cold winters and also of a dry season; (3) those plants such as the coniferous trees of high latitudes (microtherms) which thrive with short summers and long cold winters if the mean annual temperature is above freezing; and (4) the lowly plants of polar regions (hekistotherms) where the average temperature is below freezing. The fifth plant group is that of the xerophytes, mentioned in the previous paragraph. Native vegetation thus affords a basis for the division of the earth into climatic provinces. Also, the natural vegetation of a region is an index of the suitability of the region for agricultural use.

Climate and Crops

Temperature and rainfall are as fundamental in the geographic distribution of the staple agricultural crops as in the diffusion of the native vegetation. There are, of course, other factors in crop distribution, mainly economic considerations. Crop boundaries are not rigidly fixed by climate. There are two reasons for this. First, the climatic boundaries themselves are usually broad transitional zones rather than sharp dividing lines, and, second, the climatic requirements of crops are not exact and inflexible. Most crops will grow under a considerable variety of temperatures and rainfall conditions. For example, corn is grown in all parts of the United States, but the region of peculiarly favorable climate is a

comparatively small area comprising a half dozen states from Ohio to Nebraska. Wheat also is grown under diverse climatic conditions and over an extensive area including all of the corn belt, but climatic considerations make it the dominant crop in certain more limited areas bordering on the corn belt.

Notwithstanding the overlapping and the wide distribution of many crops, the characteristic crops do suggest the climatic character of large zones. Bananas, rubber, and coffee suggest one large climatic region; olives, figs, and citrus fruits indicate another type of climate. A third climatic region is implied by cotton and silk, and a fourth by wheat and corn.

In addition to temperature and precipitation, two other climatic elements are of importance in connection with crop production. These are sunshine and length of growing season. All important agricultural crops require considerable amounts of sunlight to promote the chemical activity necessary to the proper development of leaves, flowers, and fruits. But different crops vary widely in the amount of sunshine required. Certain plants in various parts of the world will produce large yields of good quality only under very sunny conditions, at least during a part of their growing or fruiting periods. Palms, olives, and corn are examples of such plants. Other plants thrive better with less sun and more cloudiness and fogginess. Abundant sunshine results in high temperature of plants and soil, and promotes chemical activity, especially the production of starches and sugars. On the other hand, too much sunshine may injure the surface roots of the plant, or its pollen or fruit, and may cause wilting from too rapid evaporation. Thus, sunshine may be beneficial or detrimental, and differences in insolation are an important climatic element in relation to crop production.

Length of growing season is obviously a significant element in the distribution of crops. The season is continuous in equatorial regions, and decreases to zero in glacial climates. The average number of days between the last killing frost of spring and the first killing frost of autumn is generally used as the length of the growing season. In the United States this varies from ninety days in parts of the mountain and plateau regions of the northwest to 260 days near the Gulf coast and 365 days in small areas in Florida and California. Cotton is an important crop only where the growing

season is about 200 days or more in length; in the main corn-growing states the season varies from 130–150 days; spring wheat matures where the season is 100 days.

Limits of plant growth are also set by the average daily air temperatures, irrespective of the occurrence of frosts. For the important crop plants of middle latitudes a mean daily temperature of 43° is usually taken as the growth limit. When the mean temperature falls below 43° growth ceases and the plants enter a rest period. The growth functions begin when the daily temperature rises above 43°, and growth continues at an increasing rate until some most favorable temperature is reached. This optimum temperature is often about 70° for the staple crops, but varies widely with different species of plants. Some tropical plants require temperatures above 60° to start growth.

Temperature and moisture control the distribution of many plant and animal pests and diseases, and thus influence the distribution of crops and livestock. Large acreages of wheat are destroyed in America by rust and by the Hessian fly when weather conditions are favorable for the development of these pests. The fruit flies of subtropical climates cause much loss to the citrus fruit growers of Australia and South Africa. The tse-tse fly prevents the raising of domestic animals in equatorial Africa. Scale insects of various kinds injure all fruit and forest trees. Most plant rusts, blights, and fungi are climatically controlled.

Climate and Land Use

In deserts little use can be made of the land. Along the edges of the desert goats and sheep find sustenance, and man leads a pastoral, nomadic existence. Where the precipitation is somewhat greater, grass-covered plains furnish grazing lands for great numbers of cattle. With increasing rainfall the grasslands often give way to the humid continental areas of middle latitudes. These regions have a wide diversity of cultivated crops, such as cotton, corn, and wheat, representing an intensified land utilization. The use of land for cereals extends into higher latitudes, where the growing season is short, but in the more humid regions of these higher latitudes the principal use of land is for the production of coniferous forests.

Density of population is thus influenced by climate. The popu-

lation is sparse in arid and polar climates and dense in regions where a favorable climate results in high productivity. If one is to make the best use of the land, the crops one grows in the different regions should be well adapted to the climates of those areas. The major crop provinces have been determined by long experience, but a more nearly complete adaptation of crops to small differences of climate is a problem of agricultural climatology or agricultural ecology. The climate cannot be changed, but the yields of many crops have been increased by the choice of variety and type and by plant breeding and selection; thus the plant may be modified and adapted to its climatic environment.

Climate and Business

Climate determines whether the general character of the occupations of a region will be farming, forestry, hunting, or fishing. The ways of making a living are inseparably bound to the climatic environment. Climate influences the location of many business enterprises. Sawmills and furniture factories naturally develop near forest areas, and flour mills are usually established in wheat-producing regions. The climatically determined corn belt and its attendant heavy production of swine and beef cattle led to the establishment of the great meat-packing industries at Chicago, Omaha, and Kansas City.

Differences of climate are responsible for a large part of the commerce of the world. Because the United States lacks a tropical climate, it must import all the coffee and rubber that it uses. Again, because the United States has large areas climatically suited to cotton and wheat, it has large quantities of these products to export. In the United States and other large and diversified countries, climatic differences are important in promoting internal trade. The citrus fruits of California, Florida, and Texas are eagerly purchased throughout the nation, as are the cranberries of Massachusetts, New Jersey, and Wisconsin. The basic industry of agriculture rests on climate, and is the foundation of the prosperity of other industries. When agriculture furnishes a plentiful food supply, there is purchase and exchange of goods, and all business is stimulated. When there is drought and famine, commerce, manufacture, and all industries languish. Business and economic cycles are closely related to rainfall and crop cycles.

Climate and Health

Certain diseases were formerly attributed directly to climate, but it is generally agreed now that climate is not a direct cause of disease. On the other hand, it is equally agreed that atmospheric conditions exert a large influence on man's health and energy. There are two distinct ways in which climate causes a geographic distribution of disease and human energy—first, by affecting the distribution of disease-causing or disease-carrying organisms, and, second, by making differing physiological demands on the human organism.

Infecting agents

The infecting agents of certain diseases have a limited climatic range. Numerous insects which breed only in continuous high temperature and high humidity are transmitters of disease germs. The malaria-bearing mosquito originates in the tropics, and it is only in warm climates that this disease is important. The yellow-fever mosquito is also confined to warm regions, and frost puts a stop to yellow fever epidemics. On the other hand, the scarlet fever germ lives in cold countries and is unknown in the tropics. This will serve to illustrate one direct effect of climate on the distribution of disease. It is fortunate that some of these pathogenic bacteria are less adaptable to atmospheric changes than is man.

Temperature level

Of still wider interest in connection with the relation of climate to health is the general effect of climate on bodily functions and activities. Man as an animal organism responds to climatic influences in somewhat the same way as plants do. He is more adaptable than most plants, but his physical responses and his growth are affected by the temperature, humidity, sunshine, and wind. One of the most important of the climatic characteristics affecting bodily functions is the general temperature level to which the body must adjust itself. This is more closely represented by the sensible temperature than by the actual air temperature. The temperature felt by the body is the combined effect of the air temperature, the humidity, and the wind. The temperature level directly influences the fundamental bodily process known as *metabolism.*

Metabolism includes both the chemical breaking down of tissues by oxidation and the building up of new tissues.

In warm air it is difficult to dissipate the heat of the body, and hence metabolism is lowered; less oxygen is required because less combustion is needed to keep the body at normal temperature. Therefore, in continuously hot countries there is a general letdown of energy, and a decrease in muscular tone and mental tone; life processes become slower. During the spells of very hot weather that occur in continental climates of middle latitudes, a strain is put upon the circulatory system in its effort to keep the blood at its proper temperature, and there are deaths from heat stroke and heat exhaustion, and an increased number of deaths from heart disease and other circulatory ailments. In cold air, bodily heat is rapidly lost, and the entire process of metabolism is accelerated in order that the body may be kept warm. Thus cold climates are generally stimulating. Cold weather may be too stimulating to certain persons in certain states of health, for cold weather also puts a strain on the heart. The death rate rises in periods of extreme cold as well as in periods of extreme heat.

It is evident from the above discussion that changeableness of the weather, or, as it is sometimes called, *storminess,* is an important climatic factor in relation to health. Sudden changes in temperature call for rapid adaptations of the body. The changes are stimulating if the body is able to adapt itself completely to them. Some persons accomplish the adaptation; others are not able to meet the stress of frequent and sharp changes. The climate around the Great Lakes, with its rather low mean temperature and its frequent changes, is probably one of the most invigorating climates of the world. There is an intense climatic drive—too intense for the best health. Nervous diseases, mental breakdowns, and hardening of the arteries are more frequent in that region than in the southern states. On the other hand, there is great energy and activity and a high resistance to infection. In marked contrast to the stimulating climate of the Lake Region is the monotonous and enervating climate of the moist tropics. In rainy equatorial climates changes from day to day and from season to season are insignificant, and the loss of body heat is slow at all times. This discourages the creation of more heat by combustion within the body, and is unfavorable to physical and mental activity. The natives

of such regions are small, reach maturity slowly, and are not able to put up much of a fight against invading bacteria. The effect of this kind of climate on man is in contrast to its effect on plants, for vegetation grows luxuriantly. This paragraph summarizes briefly the conclusions reached by Mills [1] after extensive investigations of the relations of weather and climate to human health, energy, and growth.

Continued energetic activity, such as that to which the peoples of cooler climates are accustomed, appears to be impossible in those parts of the tropics where high humidity accompanies high temperature. Griffith Taylor finds that white colonization does not occur where wet bulb temperatures average above 70°. At a temperature of 90°, a wet bulb temperature at 70° indicates a relative humidity of 36%. The dark-skinned peoples who do the work of the tropics seem never to have developed enterprise and initiative. On the other hand, much could probably be done by proper sanitation and by adjustment of diet and habits of life to make life in the moist tropics more healthful and more pleasant than it is ordinarily reported to be. Also, there are large areas in the tropics where the temperature and humidity are not oppressively high which are now thinly inhabited, but which are suited to the support of a much larger settled agricultural population.

Humidity, wind, and sunshine

Because of its relation to the sensible temperature, high humidity is generally unfavorable, especially when accompanying high temperature. At air temperatures above 80°, relative humidities above 50% are uncomfortable or oppressive. At moderate air temperatures, say between 60° and 70°, the most favorable humidities are 40% to 60%. A humidity of 20% or less has a drying and irritating effect on the skin and mucous membranes at any temperature, and contributes to the development of bronchitis, influenza, and other diseases of the respiratory tract. Similarly, both high winds and quiet air test the capacity for adjustment of the bodily functions. "Certain winds will make men's temper bad." The most favorable conditions are the intermediate values—mod-

[1] C. A. Mills, "Weather and Health," *Bulletin American Meteorological Society,* Vol. 19 (April, 1938) pp. 141–151.

erate humidities and gentle to fresh breezes. Sunshine is another element of climate directly related to health. Sunshine is essential to man, as well as to plants, and it is generally recognized that an abundance of insolation is an element of a healthful climate, but under certain conditions sunshine may be too intense.

The most healthful climates are obviously those which lie between the enervating and the overstimulating. They are the intermediate climates of moderate temperature with considerable daily and seasonal variability, gentle to moderate winds, abundant sunshine, and humidities of 30% to 50% by day and higher at night. In short, our bodies, although capable of enduring considerable extremes, are best adapted to average or intermediate conditions. The degree of "climatic drive" is a function of all of these elements, but it is approximately measured by the effective temperature and the storminess. By influencing metabolism and the functioning of the various organs of the body, climate has a considerable effect on man's physical development, his resistance to infection, and the general energy level of his existence. When one moves from one climate to another of different characteristics, the process of acclimatization is largely a physiological adaptation to new levels of heat production.

Climate and Culture

The preceding paragraphs have suggested some of the complex bearings of climate on soil, crops, commerce, plant diseases, and human health. The cumulative effect of these climatic pressures, which differ in different parts of the world, manifests itself in differing cultures. By *culture,* in this connection, we mean the characteristic mode of life of a group of people and their distinctive habits, beliefs, and attainments. It is obvious that the food-obtaining activities of man and his clothing and housing are closely governed by climatic requirements.

Habits of life

The Eskimos of the North adjust their activities to the cold and the snow, and to the long days of summer and the long nights of winter. They live laboriously and hazardously by hunting and fishing. They make their clothing of fur because the climate

makes fur available and warm clothing necessary. Their basic food is fish and flesh. In summer they live in conical skin tents; in winter they live either in half-underground huts entered through long tunnels, or in rounded huts made of blocks of snow. The natives of tropical Africa also do some hunting and fishing, but their daily life is very different from that of the Eskimos. They require little clothing and little shelter, and they live largely on a vegetable diet of native uncultivated fruits and nuts. Their houses are little more than thatched roofs supported by poles.

Not only in these extremes of climate but in all the varied regions of mankind that lie between the equatorial and the polar, there are obvious adjustments of habits of life to the conditions imposed by climate. The nomadic life is an evident adjustment to climate. The nomads of the deserts and steppes—whether warm or cold—have a different social and occupational pattern from that of the grape growers of France; similarly, these social and occupational patterns differ from that of the intensive truck farmers of China. In brief, the adjustments of man in obtaining his primary material needs are very largely governed by his physical environment, and especially by his climatic environment. Hence in similar climates—though widely separated and inhabited by different races—the human responses are often very much alike.

Common occupational patterns of life often lead also to similar social patterns, although the latter are not so directly responsive to climatic environment. Social customs and manners are modified by occupational patterns. Farmers, shepherds, mountaineers, and fishermen differ from each other, but have certain traits common to others of the same occupation elsewhere. The cowboys of Wyoming and the *gauchos* of Argentina behave and think alike in many ways. Primitive religious beliefs and practices often reflect climatic surroundings. The American Indians of the dry southwest appealed in ceremonial dances to the god of rains; those of the Great Plains pictured a "happy hunting ground" in a future life; and some Eskimos prayed to the spirit of the whale. Many of the best social and religious ideas of mankind have originated in semi-arid regions where a simple pastoral life encouraged contemplation, and where co-operative altruistic practices were enforced by the niggardliness of nature.

Architecture

The relation of climate to the dwellings of man has been mentioned, but something further may be said relative to the influence of climate on architecture. The use of brick in the form of sun-dried clay blocks (adobe) developed independently in many dry regions. The typical dwelling in all warm, arid, and semi-arid regions is a house made of mud or adobe with thick walls, small deep-set windows, a flat, tile-covered roof, a wide veranda, and a court or patio. Such a house keeps out the heat, but affords opportunity for open-air living in the cool of the day and open-air sleeping at night. It would be difficult to heat such a house adequately in cold climates. In cold climates the houses are typically two-story, compact, tightly constructed, and steep-roofed to shed rain and snow. This type of building developed independently in different wet climates characterized by cold winters. Greek architecture was of the spreading, colorful, warm-climate type; Gothic architecture was of more compact structure with larger windows and with provision for heating, and developed in a severer climate. True architecture which develops naturally and which is not copied is intimately molded by climate.

Political organization

Political institutions and organizations have their relation to climate. As has often been pointed out, the climatic differences which made the southern states a region of cotton plantations where slavery was profitable, and which made the northeast states industrial and a region of small, operator-owned farms, were largely responsible for bringing about our Civil War. A nation is more apt to be harmonious and successful if it has a homogeneous climate. Differences of climate make different laws and regulations advisable. In the United States it is difficult to make tariff laws satisfactory alike to the industrial east, the cotton-growing south, the wheat-growing plains, the cattle-raising Rocky Mountain region, and the fruit-growing west coast.

Energy level

It has been noted that differences in "climatic drive," as measured especially by temperature and changeableness of weather, result in different levels of energy and activity. These differences

in energy level, persisting from generation to generation, naturally result in differences in the rate of progress and advancement of civilization among different peoples. The most advanced and active nations of today are those having what we have called a stimulating climate. In particular they are those regions in the middle latitudes where the average annual temperature is between 40° F. and 70° F., and where there is considerable daily variation in weather and a still greater annual variation.

CHAPTER VIII

The Classification of Climate

The condition of the air at a given time and place—that is, the existing weather—can be measured and stated in exact terms; climate cannot be so measured and stated. Climate, which represents a complex and abstract idea, and which has no concrete existence at a given instant, is not something that can be evaluated exactly. In forming a picture of the climate at a given location, one cannot take into account the effect of all the weather changes, and it becomes necessary to simplify and generalize. The difficulty increases when we attempt to describe the climate of a considerable area, for the climate changes with the location and is not exactly the same in all parts of even a small area.

In considering the larger aspects of climatic differences, it is evident (1) that climates differ markedly in different parts of the world, especially in different latitudes, and (2) that large contiguous areas have climates with many points of similarity, as do also, in some cases, areas widely separated geographically. For the purpose of examining the main climatic features of the globe, it is natural and convenient to divide the earth into areas of similar climates. Such an attempt to classify climates, although obviously useful, presents great difficulties and involves the neglect of much detail, for the earth is not in fact marked off into fixed compartments of distinctly different climates. There are overlapping characteristics, and there is always a transition zone, sometimes narrow, more often broad, separating one type of climate from another. Moreover, the boundaries of these transition zones are not fixed but moving; they vary from year to year as the result of secular fluctuations of climate. A given locality may have fifteen inches of rain one year and be semiarid; another year it may receive twenty-five inches and belong in a more humid classification. One year it may have a short growing season, another year a much longer period of growth.

Bases of Climatic Classifications

Because of the many and intricate relations of climate to the physical features of the earth, to plant life, and to the life of man, many methods of dividing the earth into climatic types present themselves. These relations are the natural foundations upon which to build an orderly grouping of the climates of the earth into types or classes.

Classification by climatic controls

Some indications of simple classifications of climate based on climatic controls have been given in previous chapters.

(A) Latitudinal zones, bounded by the Tropics of Capricorn and Cancer and the Polar Circles, are astronomically determined zones of solar elevation. These made the old division of the earth into torrid, temperate, and frigid climates. It is a very crude and inaccurate division for climatic purposes. Not all areas between the Tropics are "torrid," and many places between the Tropic of Cancer and the Arctic Circle are far from "temperate."

(B) In connection with the distribution of land and water areas, it has been noted that climates may be grouped as *continental, marine,* or *coastal.* The differences indicated by the use of these terms are important, and contribute much to an understanding of the climates of the world. These terms are retained in the more detailed classifications of climate.

(C) Similarly, in relation to elevation, mountains and plateaus have certain climatic characteristics distinguishing them from lowlands. These distinctions are valuable, but they do not of themselves afford an adequate basis of classifications, for, in particular, there are lowland climates of many types.

(D) Finally, the prevailing wind systems of the world are marked by climatic differences, and we may speak of *doldrum, trade wind,* and *prevailing westerly climates.*

In each of the cases mentioned above there are certain broad, general similarities of climate, but there are also large differences within each class. For example, some continental interior lowlands are hot and others are cold; some are wet and some are dry. In cold dry continental climates there are differences in seasonal

distribution of rain, in length of growing season, and in other important climatic elements. Similarly, the other divisions mentioned above show differences that call for subdivision in various ways.

Classification by temperature

Temperature is one of the two most important climatic elements because of its controlling influence on plant and animal life. A division of the earth into areas or zones of similar temperature conditions is, therefore, a natural and logical procedure, and is in fact one basis used, directly or indirectly, in all modern classifications of climate. An early simple temperature classification first used by Supan was as follows:

(a) Hot belt—in which the mean annual temperature is 68° F. (20° C.) or higher. This is a central zone of irregular outline, considerably larger than the zone inclosed by the Tropics.

(b) Cold caps—polar zones in which the temperature of the warmest month is less than 50° F. (10° C.). In the Northern Hemisphere this cap extends north of the Arctic Circle over the continents and far south of it over the oceans.

(c) Temperate belt—the central zone between the hot belt and the cold caps.

More recently, Rubner has divided the climates of Europe, including the mountain climates, into zones on the basis of the number of warm days. A warm day is defined as a day with mean temperature above 50° F. No tropical zones are included in this classification. Rubner's European zones are:

Zone	*Number of warm days*
Subarctic	1–60
Cool	61–120
Temperate	121–180
Warm temperate	181–240
Warm	241–300

Further study of the relationships between plant growth and mean monthly or mean daily temperatures by Köppen and many others has led to further knowledge of the significance of certain limiting temperature values in connection with the growth and distribution of plants. It has been found that many tropical plants do not thrive when the mean temperature of any month

falls below 64° F. (18° C.), and that frosts do not occur when the monthly means are above 64°. Hence, instead of using the mean annual isotherm of 68° to inclose a hot belt, as Supan did, tropical regions are now usually limited by the requirement that the normal temperature of all months be above 64°.

The isotherm of 50° for the warmest month, as used by Supan, corresponds fairly well with the poleward limit of trees and the more hardy food crops. These require at least one month with mean temperature above 50° to thrive and mature. Hence a monthly mean of 50° is used as a climatic index, and months above 50° are spoken of as *warm months.* However, most plants of middle and higher latitudes begin growth in spring when the mean daily temperature reaches 43°, and they cease growth in the autumn when the daily means fall below that value. The potential growth period in a given locality is, accordingly, that period when the normal daily temperature is 43° or more, and regions in which the mean temperatures are continuously above 43° are regions of continuous growth. In the daily records made by the United States Weather Bureau, mention is made of all frosts that occur in spring after the normal daily temperature reaches 43°. Before that date it is assumed that growth has not started and that frost is not significant.

In continental climates of the United States and in similar climatic regions elsewhere, some additional temperature relations are, according to Kincer, as follows: When the normal daily temperature rises above 43°, the normal minimum temperature rises above freezing. The average dates of the last killing frost in spring and the first killing frost in autumn are approximately the dates when the normal daily temperature is 55°. No killing frosts occur during the period when the daily normals are above 62°. Cotton should not be planted until the daily normal is 62°, corn may be planted when the normal is 55°, and oats and potatoes when it is 43°. For these reasons, average temperatures of about 64°, 50°, and 43° appear to be natural limiting values in relation to plant growth, and therefore in the division of the earth into climatic provinces. A mean temperature of 32° is another such limiting value, because at that temperature the soil becomes frozen and the movement of soil moisture is stopped.

These relations are useful in the division of the earth into

large climatic provinces, but it should not be forgotten that the relations of the vegetative processes to temperature are extremely complex and are by no means fully expressed by monthly or daily means. These relations differ appreciably in different kinds of plants and even in the same plant at different stages of its life history. The temperature most favorable for vegetative growth is often considerably lower than that which is most favorable for the formation of flowers or the production of fruit. Hence, the geographic limits of a species may be set by inadequate heat during the period of seed production, and the distribution is then closely related to the mean maximum temperature during the fruiting period.

In general, the temperature of the coldest month largely governs the distribution of tropical plants, and summer temperatures govern the distribution of hardy plants. However, the length of the cold season is often a major consideration, and extreme temperatures may be of more importance than average values. The distribution may be limited by the occasional occurrence of low temperatures that kill the plants, or by early frosts that prevent them from producing seed. In parts of the Gulf Region of the United States, cold waves occasionally bring zero temperatures to localities where the mean temperature of the coldest month is above 43°. In such regions the production of subtropical crops such as citrus fruits is prevented by the rare extreme temperatures that kill the trees, rather than by the normal daily or monthly temperatures.

Classification by rainfall

Rainfall furnishes a natural basis equally as important as temperature for the subdivision of the earth into climatic zones. The simple division into arid, semiarid, and humid, corresponding broadly to desert, grassland, and forest, has been noted. A somewhat more detailed subdivision into five types may be made as follows:

Climatic type	*Rainfall type*	*Annual rainfall (in inches)*
Arid	Scanty	0–10
Semiarid	Light	10–20
Subhumid	Moderate	20–40
Humid	Heavy	40–80
Very wet	Very heavy	More than 80

It must be remembered, however, that the value of rainfall to plant growth is not accurately measured by the total annual fall. Important modifying factors are the seasonal distribution of the rain, the amount of evaporation, and the capacity of the soil to absorb what falls upon it. In certain cases the deciding factor in the distribution of plants is the length of the dry season, or the occasional occurrence of long dry periods or long wet periods.

Classification by distribution of vegetation

Because they integrate and synthesize climatic influences, plants may be used as the basis of climatic subdivisions. The following classification based on typical plant life indicates a rough subdivision of the earth into six climatic zones; the corresponding approximate mean annual temperatures are added.

1. Tropical—palms, bananas; 78°–82°
2. Subtropical—figs, myrtles; 68°–78°
3. Warm—broad-leaved evergreens; 60°–68°
4. Moderate—deciduous trees; 48°–60°
5. Cold—conifers; 40°–48°
6. Polar—dwarf shrubs, mosses, lichens; less than 40°

Pavari has divided European forests into the following major climatic zones:

	Mean Temperature ° F.	
Zone	*Annual*	*Coldest Month*
Laurel	54°–73°	Above 37°
Chestnut	50°–59°	Above 30°
Beech	45°–54°	Above 25°
Spruce	37°–43°	....
Alpine Species	Below 36°	Below 4°

These tables serve to call attention to the fact that the larger climatic types may be distinguished by their characteristic plant groups, but these relations between climate and plant life hardly form a complete or satisfactory basis for the classification of the world's climates.

Classification by physiological and psychological effects

The influences of climate on the physical and mental activities of men are evident in a broad sense, but they are indefinite and

are not known in detail. They vary widely in different individuals and in the same individuals under different circumstances. They furnish no definite criteria for the classification of climates, but the description of a climate is in fact made more intelligible and more vivid by the use of such words as *energizing, stimulating, bracing, healthful, depressing, enervating, relaxing, monotonous,* and *unhealthful.*

Microclimatology

Since temperature and rainfall are magnitudes that vary continuously between large limits, the division into types is more or less arbitrary, and can be continued indefinitely as smaller and smaller differences are considered; indeed, we might finally distinguish between the climates of adjoining farms, where, for example, one farm has a slight slope northward and the other southward. Such minute subdivisions are embraced in what is called *microclimatology,* in which small climatic differences in adjacent areas are considered. Such slight variations may arise from small differences in elevation, in direction and angle of slope, and in air drainage. These local variations are sometimes of great practical importance, as in the occurrence of frosts in valley bottoms and not on adjacent slopes. Included in microclimatology is the study of the influence of cities upon air temperature, fog, sunshine, and the dust and smoke content of the air. Local effects of forests and of small bodies of water are also subjects of microclimatic investigation.

An interesting example of a microclimatic study is that made in the Muskingum Valley in Ohio by governmental agencies under the supervision of C. W. Thornthwaite. In the 8,000 square miles of the watershed, there are 500 weather stations spaced approximately four miles apart. Each station is equipped with a recording rain gage, anemometer, wind vane, psychrometer, and thermometers. Simultaneous records are obtained from all stations at thirty-minute intervals. These records permit an intensive study of the distribution, both in time and in space, of the precipitation, temperature, humidity, wind direction, and velocity. The project was established primarily for the study of the relation of soil erosion to rainfall intensities, but it also furnishes valuable information about types of rainstorms and their internal

structure, and about small climatic variations of various kinds which may be of local value in the utilization of the land.

Köppen's Classification of Climates

The best known and most widely used classification of the climates of the world is that developed by W. Köppen during the past fifty years. Köppen first divides the land areas of the world into five major climatic divisions which are intended to correspond to A. de Candolle's five large plant groups. These are the groups described on page 105, and named by de Candolle *megatherms, mesotherms, microtherms, hekistotherms,* and *xerophytes.*

Köppen's five major climatic groups are:

(A) Tropical rainy climates. No cool season; mean temperature of coldest month above 64.4° F. (18° C.).

(B) Dry climates. Arid or semiarid; evaporation exceeds precipitation. The limits of the dry climates are determined not by the total annual precipitation, but by the amount of rainfall in relation to the temperature and to the season in which the rain falls, since both temperature and the seasonal distribution of rain influence the soil moisture available to plants.

(C) Humid mesothermal, or rainy climates with mild winters; coldest month less than 64.4° F. but warmer than 26.6° F. (—3° C.); warmest month above 50° F. (10° C.); short winters, but the ground may be frozen or snow-covered for a month or more.

(D) Humid microthermal, or rainy climates with severe winters. Warmest month above 50° F.; coldest month below 26.6° F.; long winter; ground frozen for several months; much of winter precipitation in form of snow.

(E) Polar climates. No warm season; mean temperature of warmest month less than 50° F.

These five large divisions are subdivided into a large number of climatic types in accordance with temperature differences and variations in the amount and distribution of precipitation.

The *A* climates

Köppen divides *A* climates into the following types:

Af—Tropical rainforest climate with all months wet, having at least 2.4 inches of rain each month.

Am—Tropical rainforest climate with a short dry season under monsoon influence, but soil moisture remains adequate to maintain a dense forest.

Aw—Tropical savanna climate with a distinct dry season.

These types are further subdivided by adding a third or fourth letter to indicate differences in seasonal distribution of precipitation, range of temperature, and time of occurrence of maximum temperature.

The *B* climates

Two main subdivisions of the dry climates are made:

BW—Arid climate; desert.

BS—Semiarid climate; steppe.

A small letter is added to these types to indicate differences in mean annual temperature, in the temperature of the coldest month, and in the time of least rainfall. The dividing line between BW and BS climates is determined by formulae which take account not only of the average annual rainfall, but also of its distribution through the year and of the average annual temperature.

The *C* climates

The warm rainy climates have these principal subdivisions:

Cf—No distinct dry season.

Cs—Summer is a dry season, and the driest month receives less than 1.2 inches (3 cm.) of rain. Winter is the wet season, and the wettest month has at least three times as much rain as the driest month. This is often called the *Mediterranean climate.*

Cw—Winter is the dry season. The wettest summer month has at least ten times as much rain as the driest winter month.

Differences of temperature and of time of occurrence of rain are indicated by adding a third letter.

The *D* climates

The cold humid climates are divided into Df, Ds, and Dw types, the added letters having the same significance as in the *C* climates; further subdivisions are made on the same basis as in the *C* climates.

The *E* climates

The polar climates have only two subdivisions:

ET—Tundra; warmest month below 50° F. but above 32° F. (0° C.); a brief growing season for hardy, lowly plants.

EF—Ice cap; perpetual frost; warmest month averages colder than 32° F.

Thirteen major types of climate are thus obtained, each designated by two letters, and four or five times as many minor types are obtained by adding a third and sometimes a fourth letter.

Thornthwaite's Classification

A classification of the world's climates has been made by C. W. Thornthwaite based upon the following climatic elements:

1. The effectiveness of the precipitation as determined by the ratio of the rainfall to the evaporation.
2. The temperature efficiency obtained by dividing the mean monthly temperatures by the evaporation.
3. The seasonal distribution of precipitation.

Thornthwaite recognizes five rainfall types as follows: *A*—wet, rainforest; *B*—humid, forest; *C*—subhumid, grassland; *D*—semi-arid, steppe; *E*—arid, desert. There are six temperature efficiency types: *A′*—tropical; *B′*—mesothermal; *C′*—microthermal; *D′*—taiga; *E′*—tundra; *F′*—perpetual frost. Four types of seasonal distribution of rainfall are used: *r,* rainfall abundant at all seasons; *s,* rainfall scanty in summer; *w,* rainfall scanty in winter; *d,* rainfall scanty at all seasons. Thornthwaite recognizes thirty-two types of climate, most of which are designated by a combination of three letters, one from each of the three elements just named. Actual evaporation observations that are comparable with one another are not widely available, and the values used in determining rainfall effectiveness and temperature efficiency must therefore be estimated from tables of temperature, humidity, and wind movement.

Summary

It is obvious that the main divisions or types of climate are determined by nature, largely on the basis of temperature and rainfall values in various combinations and in various seasonal distributions. It is mainly in the extent of subdivision and in the

transitions between the types that there is room for differences of opinion and practice. In any case, the boundaries are more or less arbitrary, and are in fact not lines but belts in which the climate changes gradually and irregularly from one type to another. In practice, one type of climate is distinguished from all other types by some definite and characteristic combination of the major climatic elements, temperature and rainfall.

A *climatic region* or *province* is an area in which one type of climate prevails—that is, an area in which the major climatic elements are much the same; it is not, of course, a region of complete uniformity of climate. It often happens that within a climatic region of one type there are "islands" where the climate is of another type because of local influences of various kinds.

The Köppen classification, which has the advantage of being based on definite numerical values of temperature and rainfall, can therefore be applied to any region for which temperature and rainfall data are available. (A strict application of Köppen's numerical formulae leads to unsatisfactory and inconsistent results in some cases.) Most classifications in use today are based upon Köppen with greater or less modifications according to the purposes and preferences of the author. His complete list of types becomes rather long and complicated, and in an introductory study of climate it seems desirable to concentrate on the major types, leaving the lesser distinctions for more advanced and intensive studies.

Simplified Climatic Classification

The discussion of the climates of the world in the following chapters will make use of five major divisions, based primarily on temperature differences and designated by names that are latitudinal in their implications. Under these main divisions fourteen types and six subtypes of climate will be distinguished on the basis of temperature and precipitation differences. The types of climate thus defined will correspond in general with vegetation zones or agricultural regions. In naming and describing the different climatic types, we use the following words which originally referred to types of vegetation. Because of the close correlation between climate and natural plant cover, these words have come to be applied to climatic types.

Rainforest (*selva*)—A dense forest composed of a great variety of lofty broad-leaved evergreen trees entwined by woody climbing vines, making so dense a canopy that little light ever reaches the forest floor; hence there is little undergrowth. Requires the most favorable conditions for forest growth—continuous high temperature and very heavy rainfall, in addition to good soil.

Tropical jungle (*tropical semideciduous forest*)—Tropical regions where the forest is not so dense and where the trees are not so large as in the rainforest areas. The temperature is continuously high, but the rainfall is either somewhat less than in the selvas or it is interrupted by a short dry season. Sunshine reaches the ground and promotes a dense growth of underbrush interlaced with vines and creepers. The trees and the tangled mass of undergrowth together constitute the *tropical jungle.*

Savanna—A tropical, open, level grassland of tall grasses, interspersed with trees and shrubs. The vegetation is drought tolerant—able to survive a hot dry season of considerable length.

Steppe—A large, generally level tract of semiarid land in warm or cold regions without trees, but covered with a mat of short, shallow-rooted grasses which lie dry and parched during long rainless periods and which spring into rapid growth when the rains come.

Desert—A region that is more or less barren because of insufficient moisture. Most desert areas have considerable scattered vegetation, but of types especially adapted to scanty rainfall and long rainless intervals (xerophytic plants). In limited desert areas vegetation is entirely lacking, mainly because of bare rock or shifting sand. The word *desert* as here used does not apply to areas that are barren for other reasons than lack of moisture. The rainfall is usually less than ten inches a year in deserts, but factors other than annual rainfall (mainly the relation of evaporation to rainfall) determine the actual limits of desert regions.

Taiga—A Russian word originally applied to the vast, swampy, coniferous forest region of Siberia, but now extended as a climatic term to similar regions in Europe and North America. The regions lie mainly between 50° and 65° north latitude.

Tundra—A level or undulating treeless plain, characteristic of northern Arctic regions and characteristically having a scanty cover of sedges, mosses, and lichens.

Types of Climate

- T—Humid Tropical Climates
  - TR—Tropical rainy climates
    - TRe—Equatorial subtype
    - TRt—Trade wind subtype
    - TRm—Monsoon subtype
  - TS—Tropical savanna climate
  - TH—Tropical highland climate
- ST—Subtropical Climates
  - STS—Low latitude steppe climate
  - STD—Low latitude desert climate
  - STH—Humid subtropical climate
  - STM—Mediterranean climate (dry subtropical)
- I—Intermediate (Middle Latitude) Climates
  - IS—Middle latitude steppe climate
  - ID—Middle latitude desert climate
  - IM—Humid marine (west coast) climate
  - IC—Humid continental climates
    - ICw—Warm (long summer) subtype
    - ICc—Cold (short summer) subtype
    - ICm—Modified continental subtype
- SP—Subpolar Climate
  - SPT—Taiga climate
- P—Polar Climates
  - PT—Tundra climate
  - PI—Icecap climate

Humid tropical climates

TR—Tropical rainy climates. Mean temperature of all months above 64°; daily temperature ranges greater than annual ranges; no winter; no frosts; heavy to very heavy rainfall; abundant soil moisture throughout the year.

TRe—Equatorial subtype. Occurs only within 12° of the equator and mostly within 8°, in the equatorial low pressure belt; rainfall predominantly convective; no dry season but some seasonal variation in amount of rainfall, which is usually heaviest in the trough of the doldrums as this migrates with the seasons; monotonously hot and humid; rainforest or jungle. Principal regions: Amazon Basin and the Guianas; part of the Congo Basin and the Guinea coast.

TRt—Trade wind subtype. Occurs in trade wind belts instead

of doldrums and extends poleward to Tropics and slightly beyond; hence has somewhat greater seasonal variability of temperature and rainfall than the equatorial subtype, and is less continuously humid and oppressive; rainfall is largely orographic; jungle type of vegetation; confined to islands and east coasts. Principal regions: parts of the West Indies and the Hawaiian Islands; east coast of Central America; southeast coast of Brazil; eastern Madagascar.

TRm—Monsoon subtype. Occurs where monsoons are well-developed; extends poleward to Tropics or slightly beyond; rainfall orographic from onshore monsoons; hence seasonal, with dry season during offshore monsoon (usually winter), but dry season is short and annual rainfall is sufficient to maintain a high degree of soil moisture and to support a tropical jungle. Principal regions: East Indies; Phillippines; parts of India and of the Malay Peninsula.

TS—Tropical savanna climate. Smaller annual rainfall than the tropical rainy climates; distinct dry season of two to four months during the low sun period; mean temperature of all months above 64°; annual temperature range between 5° and 15°; no frosts; natural vegetation is composed of tall coarse grasses and scattered trees; leaves fall and grasses wither during the dry season; usually form transition zones between the tropical forests and the warm steppes or deserts. Principal regions: Colombia, Venezuela, the uplands of Brazil; most of India and the interior of the Malay Peninsula; the southern Sudan; the southern part of the Congo Basin; Mozambique; northern Australia.

TH—Tropical highland climate. Plateau climates in tropical regions, generally at altitudes of 2,000 to 6,000 feet, sometimes higher; mean temperature of some months may fall below 64° but not below 43°; diurnal ranges relatively large (characteristic of plateaus), annual ranges small (characteristic of low latitudes); occasional frosts; rainfall similar in amount and seasonal distribution to that of the tropical savannas; grasslands, some forests, many cultivated tropical or subtropical crops. The most extensive region of the TH climate is in eastern Africa; smaller areas occur in the northern Andes, Central America, Mexico, and southeastern Brazil.

Subtropical climates

STS—Low latitude steppe climate. Semiarid; evaporation exceeds precipitation; long, dry, often rainless season; brief rainy period; mean annual temperature above 64°; small annual ranges; large daily ranges, especially in dry seasons; not entirely free of frost. Steppes occur as transition zones, more or less surrounding desert areas in all the continents. Vegetation: short grasses, thorny bushes, acacias.

STD—Low latitude desert climate. Arid; rainfall irregular; some years rainless; mean annual temperature above 64°; annual range large for latitude; diurnal range large; soil and air heat rapidly by day, cool rapidly by night; percentage of sunshine high, relative humidity low. Vegetation: scattered drought-tolerant (xerophytic) shrubs and cacti; some quite barren areas. Occurs characteristically in trade wind belts along the Tropics of Cancer and Capricorn. Seven low latitude deserts: Colorado and Sonora in North America, Atacama—Peruvian in South America, Thar in Asia, Sahara and Southwest Coast in Africa, the Australian desert.

STH—Humid subtropical climate. Rainfall moderate to heavy with rain at all seasons, usually a maximum in summer; mean temperature of coldest month above 43° but below 65°; nine to twelve months above 50°; occasional freezing temperatures; growing season 220 days or more. Typical vegetation: broadleaved evergreens, palms, citrus fruits, sugar cane, cotton. Occurs in eastern regions of continents, mainly between latitudes 25° and 35°. Principal regions: southeastern United States, Plata River region in South America, southern China, southeastern Australia.

STM—Mediterranean climate. Often called *dry subtropical.* Subhumid; annual rainfall typically between twenty and thirty inches, but some areas have less than twenty inches and a few more than thirty inches. A distinguishing characteristic is that the maximum rainfall is in winter; the summers are dry, often rainless for two or three months; rainfall is cyclonic; mean temperature of coldest month above 43° but below 65°; freezing temperatures occur some years but growth is normally continuous; hot summers, mild winters, high percentage of sunshine. Typical vegetation: grasses, bushes, shrubs, olives, grapes, palms, citrus fruits. Irrigation used extensively. Occurs on west coasts of continents, mainly between latitudes 30° and 40° (in the subtropical

high pressure belts). Principal regions: Mediterranean coastal regions and Portugal; southern and central California; central Chile; southwestern Australia; extreme southern Africa.

Intermediate climates

IS—Middle latitude steppe climate. Usually the poleward extension of low latitude steppes or deserts, but located in the interiors of continents or in the rain shadow of mountain ranges; separated from the warmer dry climates by the mean annual isotherm of 64°; large annual ranges with hot summers and cold winters; rainfall light to scanty and highly variable. Native plants: short or tall grasses, bunch grass, sage brush, mesquite. Crops: wheat, sorghums. Grazing of cattle and sheep important. Location: Great Plains of the United States and Canada; the Columbia Plateau; southern Russia, southern Siberia, parts of Mongolia; small areas in extreme southern portions of South America, Africa, and Australia.

ID—Middle latitude desert climate. Like the middle latitude steppes, but precipitation even more deficient; similarly situated in the interior of continents in most cases, and almost surrounded by mountains; without rain for long periods. Vegetation: scattered thorny bushes and cacti. Some grazing; no crops except under irrigation. Location: southwestern United States, Patagonia, Russian Turkestan, Sinkiang, Mongolia.

IM—Humid marine climate. The marine character is the outstanding feature of this type; winters are abnormally mild for the latitude, and summers are cool; name limited to areas where the annual range of temperature is not over 36°; temperature of coldest month above 27°; usually four to seven months above 50°; growing season 175 to 250 days. Rainfall moderate to heavy, adequate in all months, heaviest in autumn or winter; cyclonic and orographic. Vegetation: large forests of hardwoods and conifers; much hay and pasture land. Occurs typically in west coast areas between latitudes 40° and 60° in belts of the prevailing westerlies. Principal regions: western Europe from northern Spain to Norway; west coast of North America from northern California to southern Alaska; southern Chile, New Zealand, Tasmania, southern Iceland.

IC—Humid continental climates. Mean temperature of cold-

est month below 43°; none to five months below 32°; three to nine months above 50°; hot summers, cold winters, annual range greater than 36°; growing season 90 to 220 days; rainfall moderate; rain in all months, maximum in summer, often in early summer. These climates occur in the interiors and on the east coasts of North America and Eurasia between latitudes 33° and 60°. The three subtypes are:

ICw—Warm subtype. Mean temperatures: coldest month below 43°; none to three months below 32°; six to nine months above 50°. Growing season 140 to 220 days; rainfall mostly between twenty and forty inches with summer maximum; typical native trees are oak, maple, hickory. Crops: cotton and tobacco in southern portion to corn and winter wheat in the north. Location: United States from Oklahoma, Kansas, and Nebraska eastward to Virginia, Pennsylvania, and New York; Europe in Danube and Balkan regions and northern Italy; Asia in northern China, Manchukuo, and Chosén.

ICc—Cold subtype. Mean temperature of four or five months below 32° and four or five above 50°; growing season 90–140 days; rainfall fifteen to forty inches, summer maximum. Native vegetation: prairie grasses, deciduous forests, some conifers; poleward limit of deciduous forests. Typical crops: spring wheat, hay and pasture. Location: Minnesota and Manitoba to Maine and New Brunswick; Baltic Sea eastward across central Russia.

ICm—Modified continental subtype. East coast modification of humid continental; some marine influence; cooler summers and less severe winters; mean temperature of five to seven months above 50°; none to four months below 32°; fairly even distribution of precipitation through the year, with heavy winter snows. Vegetation: deciduous forests of chestnut, oak, birch, beech, maple, some conifers. Crops: oats, rye, buckwheat, potatoes, cranberries. Location: Atlantic coastal region of North America from Virginia to New Brunswick; northern Japan.

Subpolar climates

SPT—Taiga climate. Mean temperature of one to three months above 50°; six or more months below 32°; growing season less than ninety days; rainfall about ten to twenty inches, but soil constantly moist. Occurs in Northern Hemisphere only, mostly

between latitudes 50° and 65°; extends from Alaska to Labrador, and from Scandinavia to Kamchatka. Extensive coniferous forests in southern portion, becoming scrub and reaching the poleward limit of trees at northern boundary; some patch farming of barley, rye, potatoes, and berries. Lumber and furs are the chief resources.

Polar climates

PT—Tundra climate. Average temperature of warmest month below 50° but above 32°; extremely long and cold winters; short, raw, and chilly "summers" with possibility of frost at any time; subsoil permanently frozen and summer thawing results in bogs and swamps, although annual rainfall is mostly less than ten inches; extends from the poleward limit of trees to the poleward limit of any general plant life. Vegetation consists of low bushes, mosses, sedges, lichens. Location: along the northern borders of North America and Eurasia; coastal plains of Greenland; northern Iceland.

PI—Icecap climate. Mean temperature of all months below 32°; permanent covering of snow and ice; no vegetation; little is known of details of temperature and precipitation, but mean annual temperatures as low as —20° occur, and precipitation is probably generally less than ten inches. Location: interior Greenland, Antarctica.

PART II

The Climates of the World

CHAPTER IX

General Climatic Features of North and Central America

America from Panama northward has a latitudinal extent of 75°. At its southern extremity it is only 8° from the equator; at the north in Ellesmere Island and Greenland it is less than 8° from the pole. The main continental mass is roughly triangular with a broad base at the north and an apex in Central America. From Labrador to Alaska it extends through 110° of longitude, from about 55° W. to 165° W. In the west portions of the continent, high mountain systems, trending north and south, are practically continuous from Panama to Alaska. On the east and northeast are discontinuous low mountain systems and uplands of small climatic significance except locally. Between these highlands of the east and west are broad plains and lowlands extending from the Gulf of Mexico to the Arctic Ocean. In the United States they are drained in the main by the Mississippi River and its tributaries. In Canada the drainage is mostly northward into the Arctic Ocean or into Hudson Bay.

The western cordillera is an effective climatic barrier preventing the inland extension of marine influences from the Pacific. The absence of transverse barriers permits the free interchange of air between the tropical Gulf and Caribbean regions and the polar regions of the north. Within this North American region there are areas representing all of the fourteen types of climate of the world listed in the previous chapter.

Pressure

On the map of the general pressure belts of the world (Fig. 12), it will be noted that the mean annual pressure is high across the central portion of North America from east to west, and moderately lower in northern and southern portions. Seasonal changes

in the distribution of pressure are great over large continental areas, however, and they are of much significance in interpreting the climate of such areas. Figs. 23 and 24 show the mean sea-level pressures and prevailing winds in the North and Central American regions for January and July, respectively.

Winter pressure distribution

In January (Fig. 23) a distinct and broad belt of high pressure, running east and west, crosses the United States; indeed, it includes almost all of the United States within the isobars of 30.1 inches. From this belt a ridge of high pressure extends northwestward across western Canada to the Arctic Ocean. Within the extensive region included between the isobars of 30.1 inches there are in general only slight variations in the mean January pressure, but there are three comparatively small areas where the pressure equals 30.2 inches. One of these is the Mackenzie Valley in northwestern Canada, the second is the northern plateau region of the United States, comprising southern Idaho and parts of adjacent states, and the third, in the southeastern states, includes parts of Alabama, Mississippi, and Tennessee. Only the latter area is in the normal latitude of the high pressure belt.

The building up of high pressure far to the northward in interior Canada is closely related to the development of deep centers of low pressure in the Pacific in the vicinity of the Bay of Alaska and the Aleutian Islands, and in the Atlantic near Greenland and Iceland. Both highs and lows are the result of the strong temperature contrasts between land and water areas. As the land cools with the advance of winter, the air above it cools and contracts, and the more expanded air over the abnormally warm water brought by the Kuro Shio and the Gulf Stream flows inland aloft. Thus there is an accumulation of air over the land and a decrease of air over the oceans.

Summer pressure distribution

In summer, as represented by the July chart, Fig. 24, the situation has changed materially in response to the latitudinal shifting of the belts and the altered temperature relations between land and water areas. The centers of high pressure are now over the oceans, and are well-developed there, but no definite belt connects

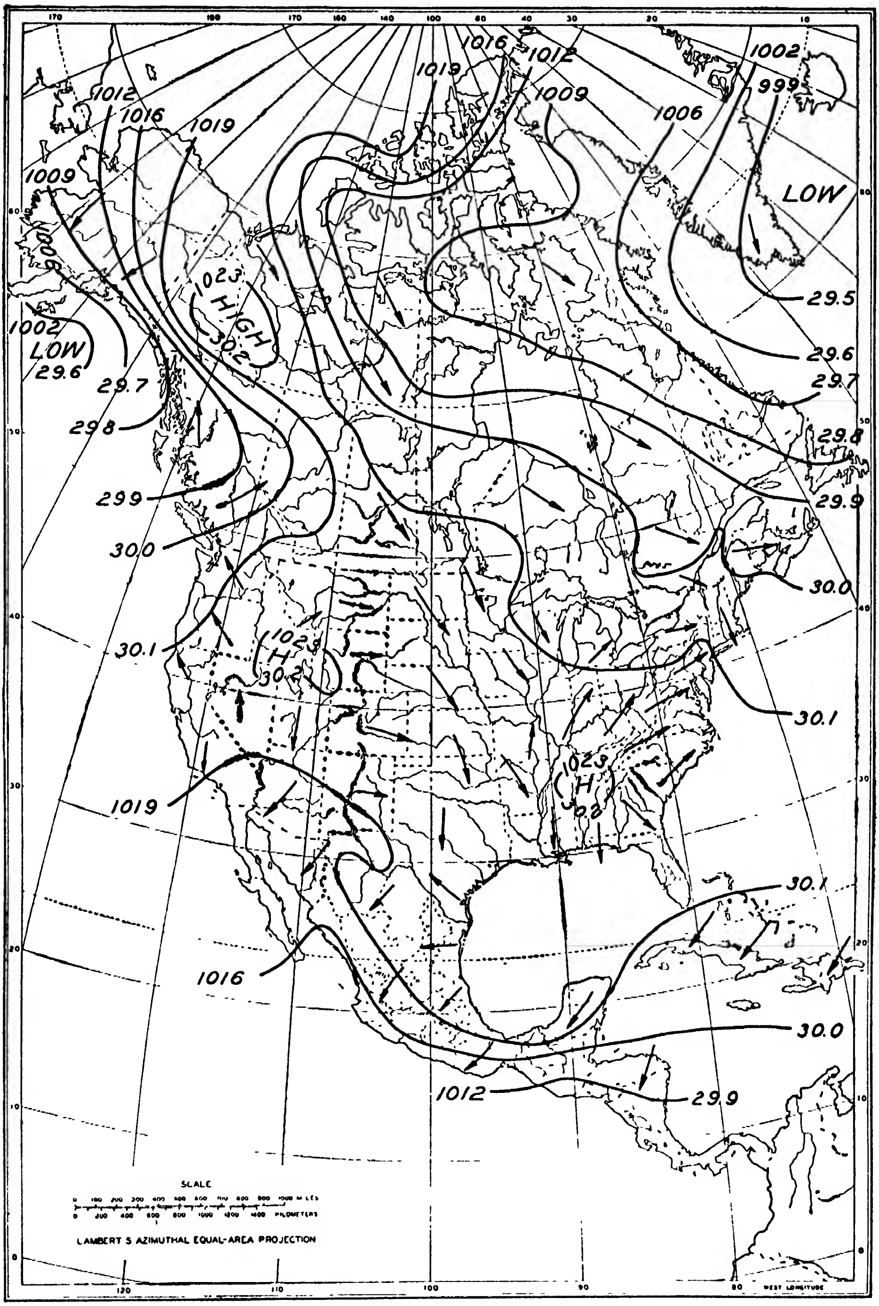

Fig. 23—Mean January Sea-level Pressure (inches and millibars), and Prevailing Winds, North America. (Base map by permission of the University of Chicago Press.)

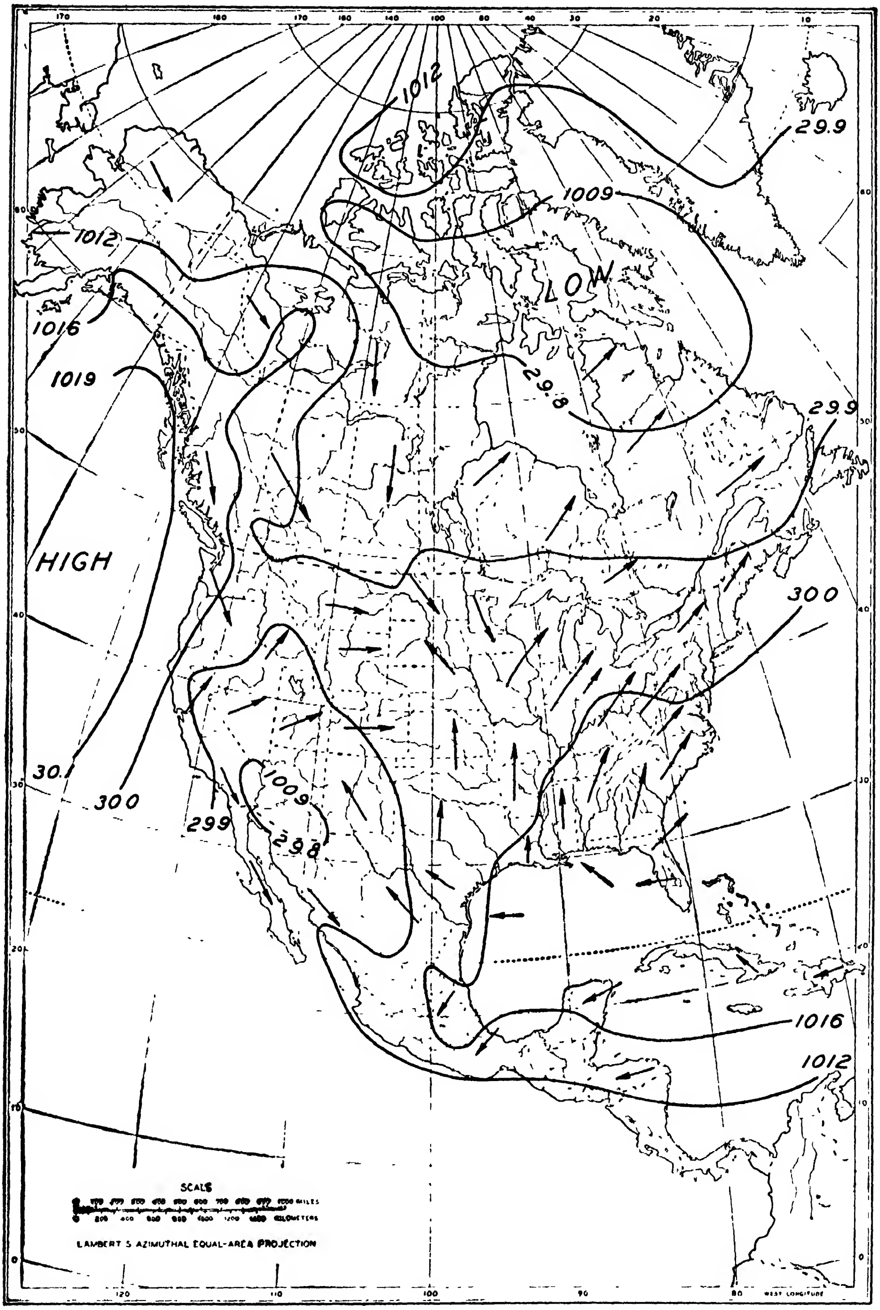

FIG. 24—Mean July Sea-level Pressure (millibars and inches), and Prevailing Winds, North America. (Base map by permission of the University of Chicago Press.)

them across the continent. The areas of highest pressure over the land are now along the Pacific coast from Puget Sound to southern Alaska, on the edge of the Pacific high, and in the southeastern states and the West Indies as a landward extension of the Azores high of the Atlantic.

The polar circle belt of low pressure is evident from Alaska to western Greenland with the center of lowest pressure over Baffin Island and Davis Strait, but it is much weakened over the oceans. The entire interior of the continent now has relatively low pressure. Pressure is especially low in the semiarid and arid southwest, including northern Mexico; this is caused in large part by the high summer temperatures. In the remainder of Mexico and in Central America and the West Indies changes in pressure between summer and winter are slight.

Winds

The changes in wind direction attending these changes in pressure are an important element of the climate. Mexico, Central America, and the West Indies are in the northeast trade-wind belt; the United States and Canada are in the belt of the prevailing westerlies, which undergo much seasonal modification. Polar easterlies develop in Greenland and, at times, along the extreme northern border of the continent.

Prevailing winds of winter

In winter the general movement of air is outward from the areas of higher pressure in the interior of the continent toward the lower pressures of the adjacent oceans. In particular the cold air of the Mackenzie Valley region moves southward and eastward. Hence, winter winds are prevailingly from the northwest in the great central valleys of the United States and from the west or northwest in the north Atlantic states and eastern Canada. In the north Pacific states and western Canada, winds are mostly from the southeast, south, or southwest, as the air moves out of the Plateau high to enter the cyclonic circulation of the center of low pressure in the Gulf of Alaska. In the vicinity of the high pressure center in the Mackenzie Valley winds are light and variable. At this season northeast trade winds of moderate velocity are almost continuous in the West Indies and the Caribbean region.

and are the prevailing winds in Florida and in most of Mexico, but winds from the interior prevail along the Gulf coast of the United States.

Prevailing winds of summer

In summer the surface air moves inland in response to the pressure gradient. Hence, winds are mostly from the south or southwest in the central and eastern states and southeastern Canada, since the center of low pressure is in the northeast. Along the Pacific coast from British Columbia to Lower California winds are most frequently from the northwest in summer, for the pressure is high off the west coast of Canada and low in southeastern United States. We thus find over a large part of the United States and southern Canada a more or less complete reversal of wind direction with the seasons. This is a true monsoon effect. The trade winds continue dominant in Central America, southern Mexico, and the West Indies, becoming east or southeast winds, rather than northeast, over much of the area, especially in the Gulf of Mexico, where they feel the monsoon influence. The trade winds are persistent, but in the belt of prevailing westerlies the surface winds are irregular and changeable.

Cyclonic control of winds and weather

The frequency of active, moving cyclones and anticyclones with well-developed wind systems and sharp temperature contrasts is a marked characteristic of the climate of the United States and Canada, especially in the winter half-year. Such disturbances in the regular flow of the air, caused by the meeting of warm and cold air masses, occur in the prevailing westerlies around the world, but in no other continent are they so frequent and active as in North America. They are especially characteristic of North America because the uninterrupted broad central plain, extending from tropical to polar regions, permits the free movement of air masses of extreme temperature differences. The width of the continent in Arctic latitudes and the abnormal winter warmth of the waters of the Gulf of Mexico contribute to these temperature contrasts. The continuous high mountain systems on the west serve to facilitate and guide the movement of cold continental air southward.

The Caribbean Sea and the Gulf of Mexico are continually supplied with warm water by the Equatorial Drift. The air over these waters becomes very warm and moist in winter as well as in summer. Changes in the general distribution of the air are frequently attended by the movement of these warm, moist air masses (tropical Gulf air) far northward into the central and eastern portions of the United States and southern Canada. They bring warm, thawing weather in winter, and hot, humid weather in summer. On the other hand, abnormally cold air (polar continental) with temperatures much below zero accumulates during the long, almost sunless winters in the regions of high pressure and light wind movement in northern Canada. From time to time portions of this cold air mass move southward from the Mackenzie Valley into the Missouri and Mississippi Valleys, and thence southward and eastward even to the Gulf coast and Florida. Similarly, cold air from the Hudson Bay region moves southward to the Great Lakes and the north Atlantic states.

In the meeting and interaction of these warm and cold air masses we get the formation of cyclones and anticyclones, and frequent and sudden weather changes. On the eastern side of the low pressure area there is a front of tropical maritime air moving eastward or northeastward. On the western side of the low and the eastern side of a following high there is a cold mass of advancing polar continental air. As the two masses move eastward with the prevailing westerlies there is first abnormally warm weather with southerly winds and then a sudden change to cold northwest winds. The advance of the warm front eastward, causing the warm air to rise over cooler air, is frequently attended by rain. As the cold front moves eastward, it underruns and elevates the warm air, and often produces rain or snow. In either case the main source of moisture is the tropical air mass from the Gulf of Mexico or the Atlantic ocean. The general and extensive rainstorms and snowstorms of the United States and Canada are the result of the interaction of such air masses, and the precipitation is therefore cyclonic in origin.

Cold waves and blizzards

In winter a fall in temperature of 20° F. or more within twenty-four hours, beginning with the arrival of the cold front of a polar

continental air mass from the Mackenzie Valley, is not uncommon in the United States and southern Canada, east of the Rocky Mountains; in rare cases a fall of 60° has been recorded. These sudden changes to very cold weather are known as *cold waves.* Occasionally, zero temperatures are thus carried southward to within 100 miles of the Gulf coast, and freezing temperatures into Florida and extreme southern Texas. The change to northerly winds and cold air is at times attended by high winds and driving snow, constituting what is popularly called a *blizzard.*

Tornadoes

A storm that is more frequent in the central valleys of the United States than elsewhere in the world is the small but destructive storm known as the *tornado.* The air whirls with great velocity about an almost vertical axis, and a pendant funnel-shaped cloud extends from the cloud base toward the earth. Where the funnel reaches the ground it spreads destruction in a narrow path generally less than a quarter of a mile in width. Tornadoes occur along an abrupt cold front, where air masses of strongly contrasting temperatures meet. Though of rare occurrence in any one community, they are a feature of the climate of the Mississippi, Ohio, and lower Missouri Valleys. The number reported in the entire United States is about seventy-five a year. They are most frequent in the afternoon in spring and early summer.

Summer air masses

In summer the temperature contrasts between Gulf and Canadian air are considerably less than in winter, and cyclones and anticyclones are much less active. Much of the cool air that invades the continental interior at this season comes from the high pressure area of the north Pacific ocean rather than from Canada, and is of moderate temperature. Air that moves northeastward from the arid southwestern states (tropical continental air) is hot and dry in summer, and constitutes the "hot winds" that injure crops in the Great Plains and sometimes in the Mississippi Valley. But cyclones that move inland from the southwest are attended on their eastern sides by warm, moist (tropical maritime) air from the Gulf of Mexico or the Atlantic Ocean. This air is the source of most of the precipitation of central and eastern United States.

Temperature

The main features of the actual average temperatures (not reduced to sea-level) are shown for January in Fig. 25 and for July in Fig. 26. In the January chart the north-south trend of the isotherms, paralleling the Pacific coast line from Central America to Alaska, and the crowding together of the lines inland, indicate the influence of the warm air from the Pacific, the barrier effect of the mountains, and the effects of elevation. The crowded isotherms along the Gulf coast of the United States and northern Mexico show the influence of the warm water of the Gulf. The modifications due to the Atlantic along the eastern border of the continent are much less marked.

The accumulation of cold air in the interior during winter is indicated by the southward bending of the isotherms. The Great Lakes mitigate the winter temperatures in their vicinity 5° to 10°. The moderate temperature of the Plateau region of the United States as compared with the temperature of the central valleys in the same latitude and at a lower elevation is evidence that the plateau escapes much of the polar continental air. Most of such cold air masses move southward east of the Rocky Mountains and do not spread westward. The plateau of Mexico is about 5° to 10° colder than the coastal lowlands. The lowest mean temperature is about —40° over the icecap of Greenland.

In July the rise in the temperature of the interior is marked and increases rapidly northward. In Texas July is 30° warmer than January; in North Dakota the difference is 65°, and in north-central Canada, 80°. In contrast, the cooling and stabilizing marine influence is evident on all coast lines. Along the Pacific coast the change from winter to summer is 5° in Central America, 10° in the United States, and 20° in Alaska. The cooling effect of elevation is also shown in the highland areas from southern Mexico to British Columbia.

In July the mean temperatures vary from about 80° in Central America and the West Indies to 40° in the northern islands of Canada, a difference of only 40°. In January, comparing the same areas, the range is from 75° to —30°, a difference of 105°. Interior Greenland is the only area where the mean summer temperatures remain below freezing. The hottest region is a small area in

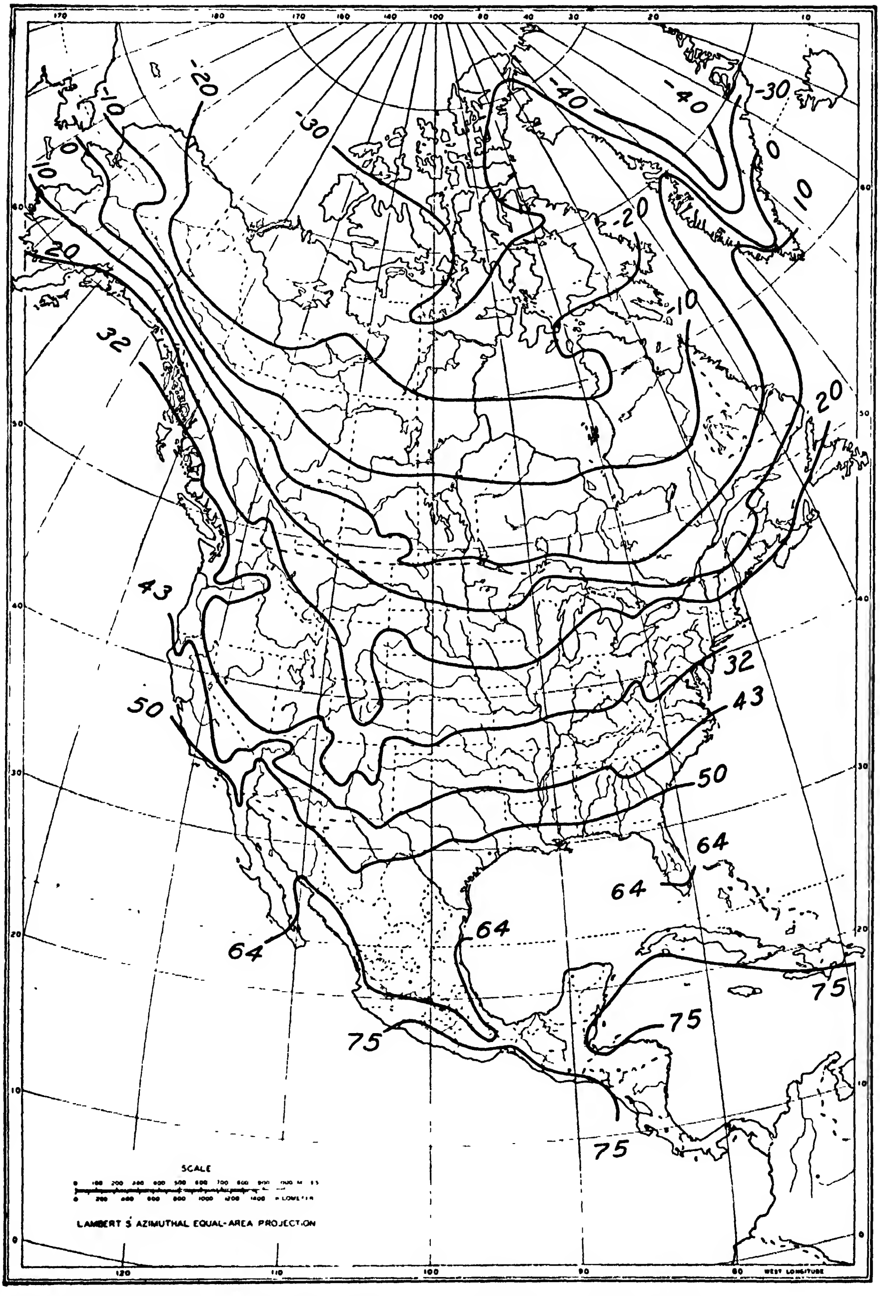

FIG. 25—Mean Actual January Temperatures, °F, North America. (After Brooks and Connor, and Kincer. Base map by permission of the University of Chicago Press.)

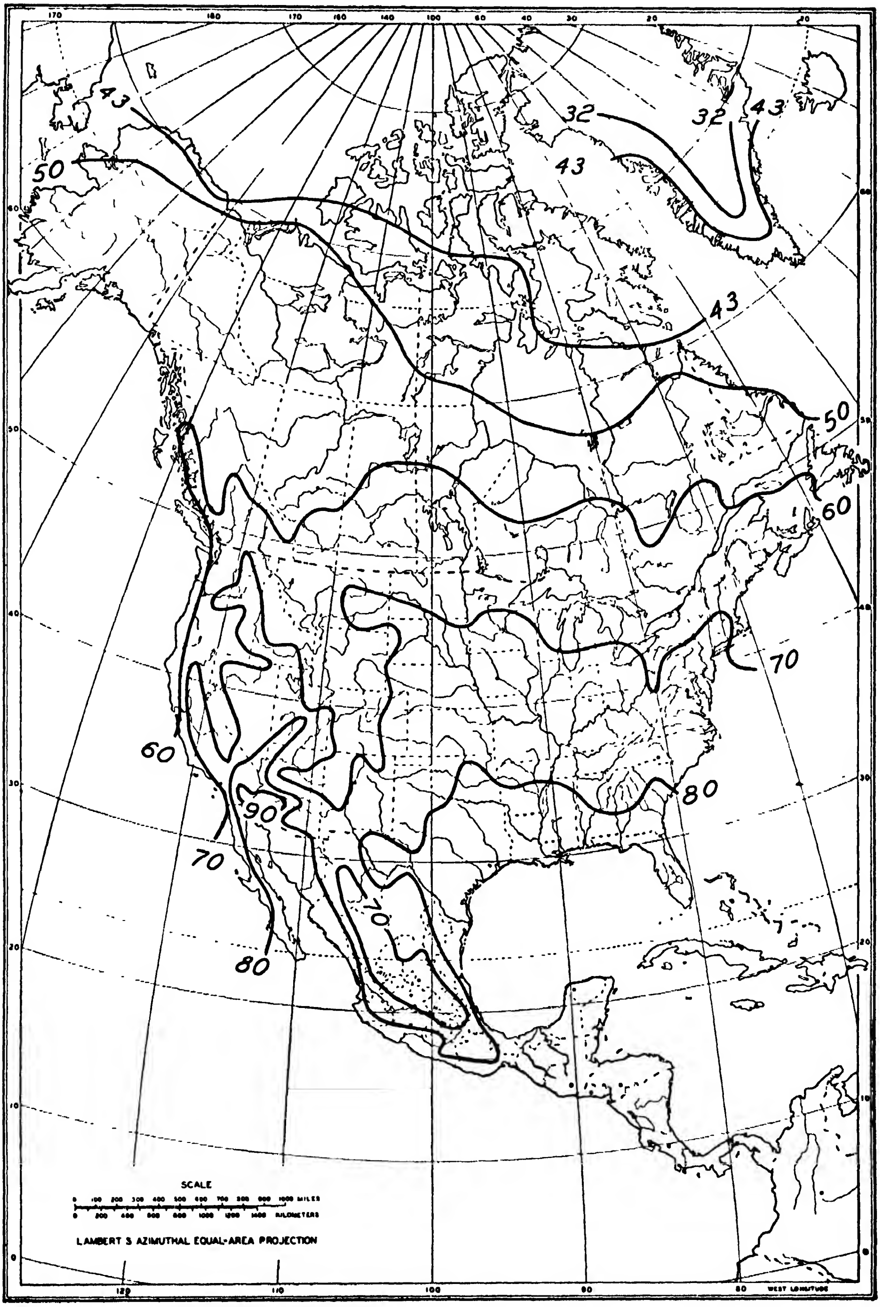

FIG. 26—Mean Actual July Temperatures, °F, North America. (After Brooks and Connor, and Kincer. Base map by permission of the University of Chicago Press.)

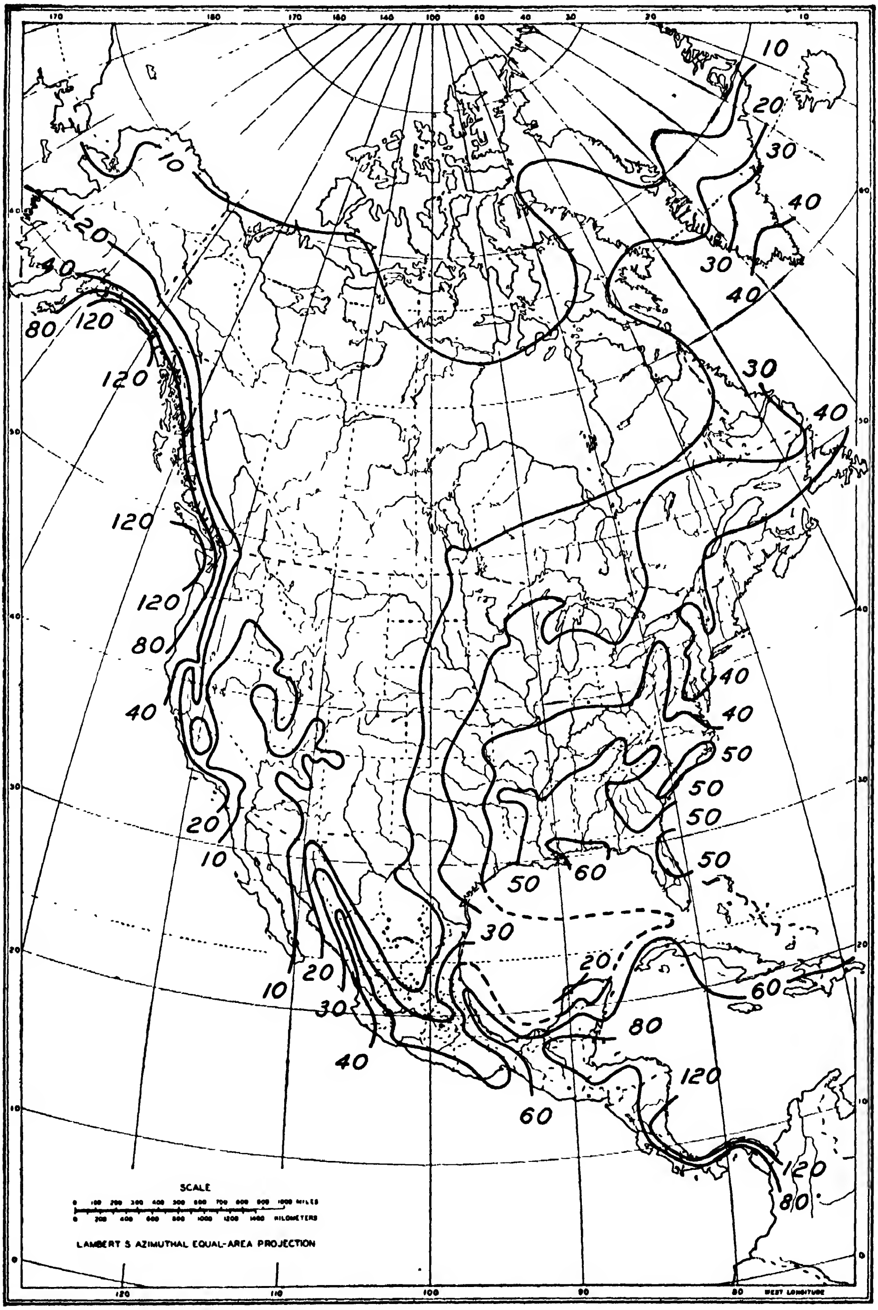

FIG. 27—Mean Annual Rainfall (inches), North America. (After Brooks and Connor, and Kincer. Base map by permission of the University of Chicago Press.)

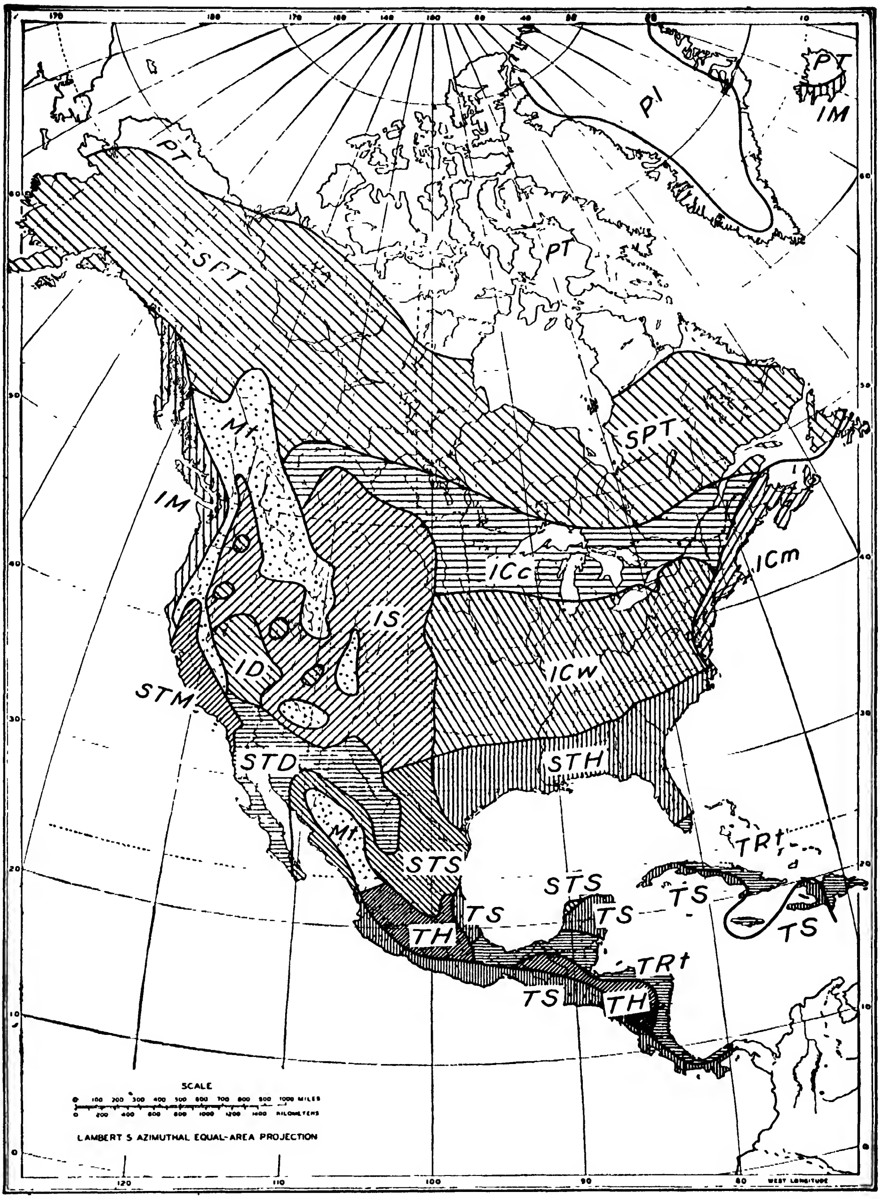

FIG. 28—Climates of North and Central America. (Base map by permission of the University of Chicago Press.)

TRt—Tropical Rainy (trade wind subtype).
TS—Tropical Savanna.
TH—Tropical Highland.
STS—Low Latitude Steppe.
STD—Low Latitude Desert.
STH—Humid Subtropical.
STM—Mediterranean.
ID—Middle Latitude Desert.
IM—Humid Marine.
ICw—Humid Continental (warm subtype).
ICc—Humid Continental (cold subtype).
ICm—Modified Continental.
SPT—Taiga.
PT—Tundra.

the desert of southeastern California and southwestern Arizona, where July temperatures average 90°. The interior of the United States and Canada has an extreme continental climate; the Atlantic coast has a modified continental climate, and a narrow belt on the Pacific coast has a definitely marine climate.

Rainfall

In the chart of mean annual precipitation (Fig. 27) note the heavy rainfall in all the regions south of the Tropic of Cancer, except in small areas in the Mexican plateau. There is much convectional rain in these latitudes, but note that the rainfall is heaviest on the east coasts and east slopes—that is, on the windward coasts and slopes in this trade wind belt. Hence, it is evident that orographic influences are important. Observe the crowding of the lines along the Pacific coast from California to Alaska, and also the increased rainfall from south to north becoming very heavy in places on the western, windward slopes of the Coastal, Sierra Nevada, and Cascade Ranges. The rains occur in connection with cyclonic activity, but are increased in amount by the movement of the air up slope. The rain shadows east of the Sierra Nevada and Cascades are pronounced, resulting in large areas of steppe and desert.

Between the Mississippi River and the Appalachian Mountain system, the rainfall decreases with considerable regularity from sixty inches at the Gulf coast to ten inches in northern Canada; this may be attributed to decreased temperature and increased distance from warm water, both of which tend to reduce the moisture content of the air. In the Great Plains the decrease in rainfall is from east to west, largely because of the rain shadow effect of the Rocky Mountains. This effect is greatest at the leeward bases of the mountains and decreases eastward. Thus, the isohyets have a north-south trend. Throughout the interior and eastern portions of the continent, the rainfall is largely cyclonic in origin, but in the warmer portions there is considerable convective rain in summer.

CHAPTER X

The Humid Tropical Climates of Central America, Southern Mexico, the West Indies, Southern Florida, and Hawaii

All three of the humid tropical types of climate (rainy, savanna, and tropical highland) are represented in the land areas bordering that portion of the Gulf of Mexico south of the Tropic of Cancer, or bordering the Caribbean Sea exclusive of the Caribbean coast of South America. The same three types occur in the Hawaiian Islands.

Tropical Rainy and Tropical Savanna Climates of the Gulf and Caribbean Regions

Physical features

A chain of mountains and plateaus extends from Costa Rica northwestward through the Central American countries into southern Mexico to about latitude 18° N., giving to the interior portions of Costa Rica, Nicaragua, Honduras, El Salvador, Guatemala, and southern Mexico large areas between 2,000 and 6,000 feet in elevation. Large parts of these plateaus are arable, comparatively level land. Between latitudes 18° and 20° an irregular, mountainous region crosses Mexico from west to east. North of this region the Sierra Madre Oriental begins near the Gulf coast and extends northwest to the northern border of Mexico, where it connects with the Sacramento Mountains of New Mexico. Near the Pacific coast, the Sierra Madre Occidental extends northward into Arizona. Between these ranges lies the great central plateau of Mexico having an average elevation of about 3,000 feet and rising in the south to about 8,000 feet. Bordering these highland regions, on both the Atlantic and Pacific sides, are fringes of coastal lowlands generally about thirty to forty miles wide, but widening in places and including also most of the Isthmus of Yucatan. Back

of these sandy, ill-drained coastal plains, a fertile, talus slope with luxuriant, tropical vegetation leads to the highlands.

Pressure and winds

In this region the trade winds are in general persistent throughout the year. The July pressure chart (Fig. 24) shows the lowest pressure off the southwest coast of Central America, marking the northward migration of the doldrums. The pressure increases northeastward to Bermuda. This pressure distribution is favorable to northeasterly and easterly winds over the entire region, but pressure differences are small and winds are influenced along the west coast of Central America and Mexico by the summer heating of the interior. On a part of the Pacific coast, the sea breeze blows inland daily during the heat of the day, and in some localities winds are prevailingly from a westerly direction. In January, pressure is lowest in the south and there is a maximum of pressure over the southeastern United States. Pressure gradients are considerably steeper than in summer, and are less affected by local conditions, resulting in steady northeast trade winds of moderate strength.

The trade winds, as they move over the oceans, are warm winds carrying a large amount of moisture but with only a moderate relative humidity, since they are traveling into warmer latitudes and are acquiring an increasing capacity for moisture. When these winds move against elevated regions, the forced ascent results in adiabatic cooling and copious condensation. As they move down slope on the leeward sides of mountains, they become very dry winds, because they have lost much moisture on their upward course and because they are adiabatically warmed as they descend. In the Gulf and Caribbean regions during the cooler months, the constant uniform movement of the trades against the eastern slopes produces a slow, steady orographic type of rain. In the summer months, when the trades are weakest and when local differences in temperature and wind direction are greatest, there is much convectional rising of moist air and heavy rain of the thunderstorm type.

As a consequence of these relations of the rainfall to wind direction, temperature, and elevation, the eastern coast lands of Central America and southern Mexico, and the windward slopes of

the Greater Antilles have a tropical rainy climate of trade wind subtype (TRt) with ample rain in all months, usually heaviest when the sun is highest. The lee slopes have moderate rainfall, mainly summer convectional, with a distinct dry season when the sun is lowest. The climatic type is tropical savanna (TS). The West Indies are squarely in the most frequented track of the hurricanes, and these storms also occasionally invade Mexico and Central America, interrupting the regular flow of the trade winds and inducing heavy cyclonic rains. Because hurricanes are most numerous from August to November, they tend to produce a maximum of rainfall in those months. The only cyclonic rains in tropical climates are in those limited areas where tropical cyclones occur.

Rainfall in the tropical rainy regions

The tropical rainy climate, as modified by the trade winds, prevails in the Caribbean coastal plains of Central America from Panama to the southern shore of the Bay of Campeche in Mexico, omitting the greater part of the peninsula of Yucatan. This belt of lowland is narrow for the most part, but extends inland fifty to one hundred miles in Nicaragua and as much as seventy miles in parts of Honduras. The same type of climate obtains in Jamaica, in the northern and eastern portions of Cuba, the eastern half of Hispaniola (formerly Haiti), the greater part of Puerto Rico, and in the Lesser Antilles. In these areas the rainfall averages between fifty and 140 inches for the most part, the amount varying with the slope and elevation of the interior highlands and their orientation with respect to the direction of the trade winds. Much of the lowland area is flat and poorly drained, and the heavy rainfall results in many swampy areas (mangrove swamps).

The rainfall regimes of typical stations in this region are shown in Fig. 29. Note the very heavy rainfall at Colon, Bluefields, and Port Antonio, with rain in all months but with a decided maximum from May to November, inclusive. This is a period of frequent and heavy thunderstorms. At San Juan the regime is similar, but the total is much less, for here the prevailing wind is east, which in this case is not on-shore but parallel with the shore. Actually, southeast winds are more frequent than northeast winds in Puerto Rico, particularly in summer.

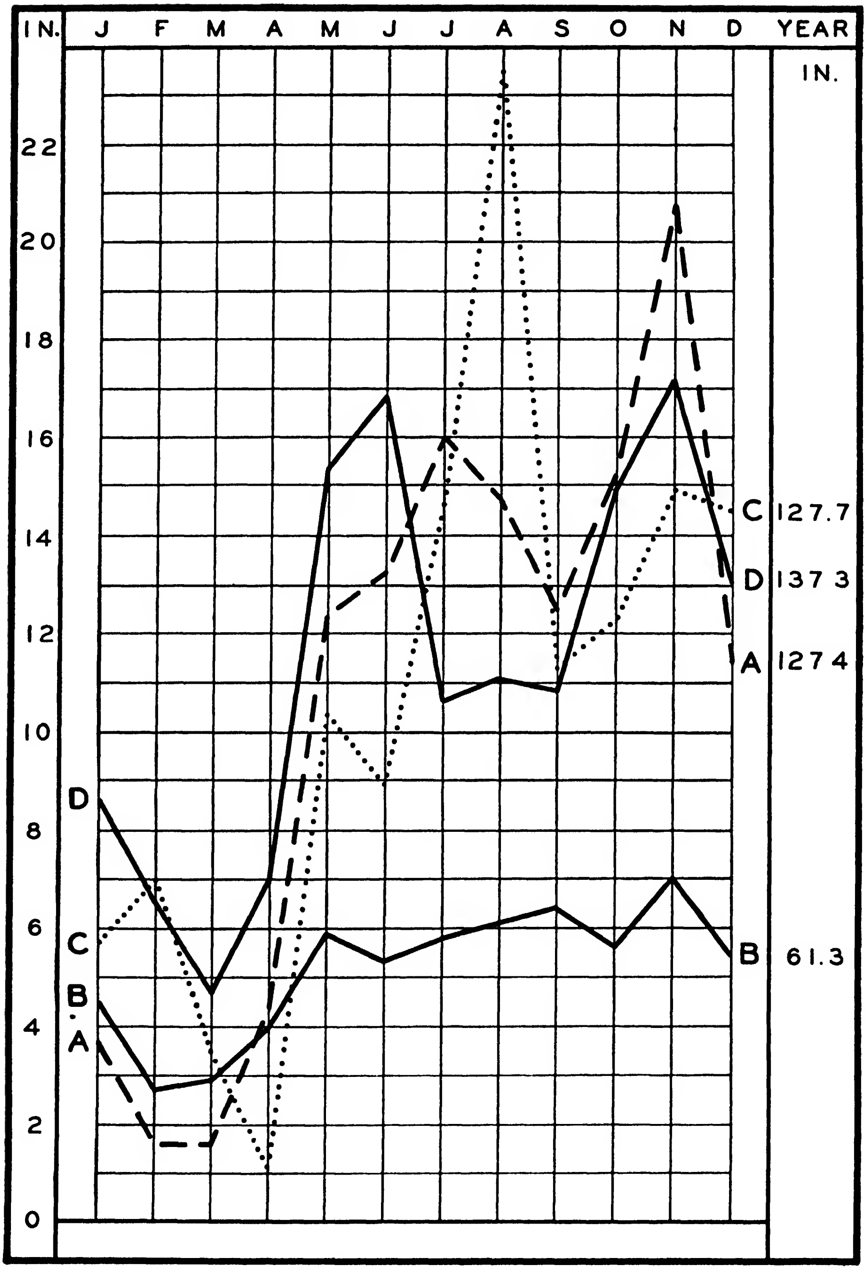

FIG. 29—Average Precipitation. Tropical rainy climate of Central America and West Indies.

A. Colon, Canal Zone.
B. San Juan, Puerto Rico.
C. Bluefields, Nicaragua.
D. Port Antonio, Jamaica.

Rainfall in the tropical savanna regions

A tropical savanna climate (TS) with a moderately heavy rainfall and with a well-defined dry season of several months' duration is found on the Pacific coast from Central Panama northward to about latitude 22° on the coast of Mexico; the same type of climate is also found in western and southwestern Cuba, in the western half of Hispaniola, and in a large part of Yucatan.

Tropical Climates of Mexico, Central America, and West Indies	*Elevation (Feet)*	*Mean Temperature °F.*				*Average Precipitation (Inches)*		
		Year	*Coolest Month*	*Warmest Month*	*Range*	*Year*	*Wettest Month*	*Driest Month*
TRt								
Colon, Canal Zone	0	79.9	Nov. 78 6	Apr. 80 8	2 2	127.9	Nov. 21.7	March 1.5
Bluefields, Nicaragua	0	79.5	Feb. 77.7	Apr. 82 4	4.7	127 7	Aug. 23.5	April 1.1
San Juan, Puerto Rico	57	77 9	Feb. 74.8	Aug. 80.4	5 6	61.2	Nov. 7.0	Feb. 3.0
Santo Domingo, Hispaniola	59	78.4	Feb. 75 6	Aug. 81.0	5.4	57.7	Sept. 7 1	Feb. 1.3
TS								
San Jose, Costa Rica	3724	67.5	Dec. 65.8	May 68.9	3.1	75.9	Sept. 14.2	Feb. 0.2
San Salvador El Salvador	2156	73.6	Dec. 71.4	Apr. 76.3	4.9	68 0	July 12 3	Jan. 0.1
Salina Cruz, Mexico	184	79.0	Jan. 75.2	May 81.9	6.7	36.7	June 10.4	Dec. 0.4
Veracruz, Mexico	52	76.6	Jan. 70.1	Aug. 81.1	11.0	65.3	Sept. 13.9	March 0.3
Havana, Cuba	79	77.4	Jan. 71.6	July 82.4	10.8	48 3	Oct. 6 5	March 1.9
TH								
Chimax, Guatemala	4281	64.9	Dec. 60.4	June 67.8	7.4	95 4	Oct. 12.9	April 3.4
Puebla, Mexico	7054	61.3	Jan. 55.0	May 65 8	10 8	31.7	Sept. 7.4	Feb. 0.3
Mexico City	7457	61.5	Jan. 56 3	Apr. 65.1	8.8	23.0	July 4.9	Feb. 0.2
Leon, Mexico.	5935	65.8	Dec. 56.8	May 73.9	17.1	25.2	July 6.2	April 0.2

The Pacific coastal plain is narrow throughout its length. During the rainy season its climate, like that of the Caribbean coast,

is humid and oppressive, but during the drier and slightly cooler half of the year the climate is pleasant and healthful. As illustrated in Fig. 30, the rainfall is largely concentrated in a wet season, extending from June to October. At San Jose and San Salvador there are frequent easterly, on-shore winds in summer. These winds are attended by heavy thundershowers, and they result in a total of more than eight inches of rainfall each month

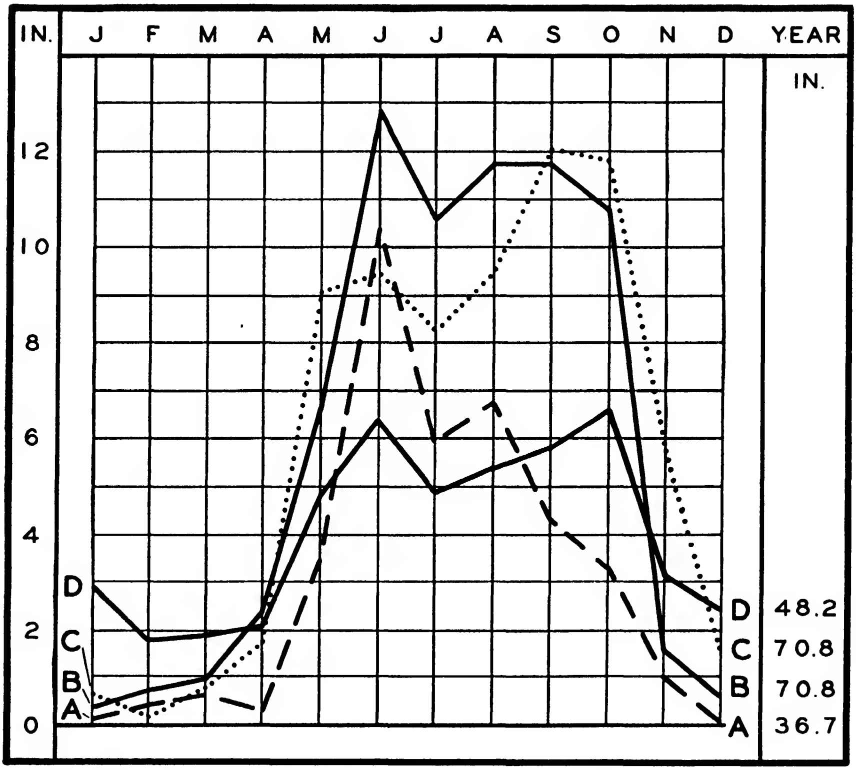

FIG. 30—Average Precipitation. Tropical savanna climate of Mexico, Central America, and the West Indies.
A. Salina Cruz, Mexico. C. San Jose, Costa Rica.
B. San Salvador, El Salvador. D. Havana, Cuba.

from June to October, inclusive. At Salina Cruz, on the south shore of the Isthmus of Tehuantepec, the winds are largely from a northerly direction. June is the only very wet month, and the annual total is less than forty inches. From December to April this Pacific lowland has steady, off-shore, descending winds, and a definite dry season. Often one or more of these months passes with no rain whatever.

In the portion of the West Indies included in this type (see graph for Havana, Fig. 30) there is some rain throughout the year, as the trade winds vary between northeast and southeast. The northward movement of the doldrums accounts for more convectional rain in summer, and the occurrence of hurricanes adds to the late summer rainfall. Also included in this climatic type are (1) Yucatan, which does not have sufficient elevation to induce heavy orographic rain, but which receives considerable convectional rainfall during the summer months; and (2) the Gulf coast of Mexico from Veracruz (lat. 19° N.) to the Tropic of Cancer, which receives trade wind rains during the summer, but which is under the influence of dry northerly winds from the United States in winter. This region is hot and moist in the rainy season, but is far enough north to have a considerable decrease in temperature in the winter months, which are accordingly very agreeable. An occasional "norther" from the United States brings a large drop in temperature that is unpleasantly cool to persons acclimated to tropical conditions.

Temperature

The portion of Central America and southern Mexico having truly tropical conditions is the coastal lowland area, on both Atlantic and Pacific sides, lying below about 3,000 feet and known as the *tierra caliente,* or *hot land.* In the West Indies practically all the habitable area is within this temperature zone. Graphs of mean monthly temperatures at four representative stations in the tropical rainy climate (TRt) are drawn in Fig. 31. Fig. 32 shows the record for four stations in the drier, leeward climate (TS). The mean annual temperatures in both groups all lie between 76° and 80°. The lowest monthly mean at any of the eight stations is 71.6° at Havana in January, and the highest for any month is 84.2° at San Juan Bautista in May. At Colon, the most southerly station, the warmest months are April and August, 80.8° each, and the coldest month is November, 78.6°, giving an annual range of only 2.2°. San Juan Bautista has the greatest annual range, the temperature rising from 72.3° in January to 84.2° in May, a difference of 11.9°. The average annual range of the eight stations is 7.3°.

Note that temperatures reach a maximum in April and again in August at Colon, in May in Central America and extreme south-

ern Mexico, in June and July farther northward in Mexico, and in July or August in the West Indies. This progressive change in the warmest period of the year illustrates the influence of vertical sun,

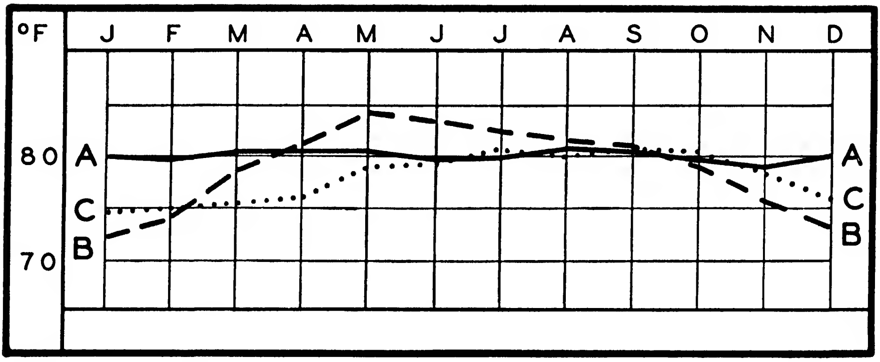

Fig. 31—Average Temperature. Tropical rainy (trade wind) climate of Mexico, Central America, and the West Indies.
A. Colon, Canal Zone. B. San Juan Bautista, Mexico. C. San Juan, Puerto Rico.

cloudiness, and rainfall upon temperatures in the tropics. The sun, which is vertically overhead at noon at the equator on March 21, then moves northward and is overhead during April in Central America, during May in southern Mexico, and finally on June 21

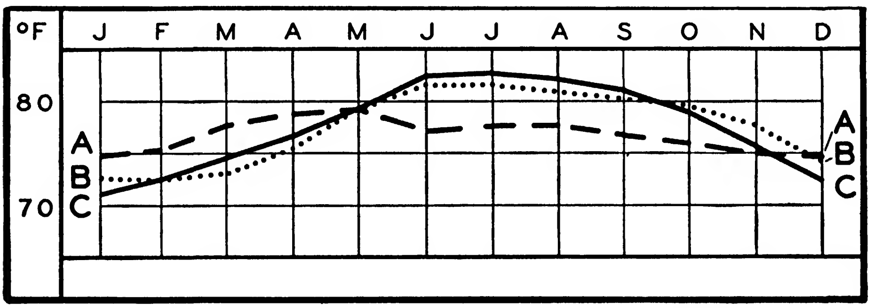

Fig. 32—Average Temperature. Tropical savanna climate of Mexico, Central America, and the West Indies.
A. San Salvador, El Salvador. B. Manzanilla, Mexico. C. Havana, Cuba.

at the Tropic of Cancer. It then starts southward and is again vertical progressively later—that is, in July in southern Mexico and in August in Central America. There are, therefore, two maxima of insolation very close together and merging into one near the Tropic, but farther apart in lower latitudes.

We should, accordingly, expect two periods of maximum temperature in Central America, as is the case at Colon. But the late

summer months are the time of greatest cloudiness and rainfall; these are effective in keeping the temperature down, and hence we find that the warmest month is May over a large area. The larger islands of the West Indies are near enough to the Tropic for the heating effect of the two periods of high insolation to merge into one. They are also much exposed to the influence of the ocean water temperature, which is at its highest in late summer. These islands, therefore, have their highest temperatures in July and August, or even September. Although temperatures average high throughout the year, there are no readings as extremely high as those sometimes experienced, for example, in Alberta, Canada. In these tropical regions the thermometer seldom reaches 95°. At San Juan, Puerto Rico, the highest temperature of record is 94° and the lowest is 62°. The average number of days per year with temperatures above 90° is only seven, and the number below 65° is two per year. The average daily maximum temperature of the warmest month is only 85.8°, but it is 80.0° for the coldest month. The highest average daily minimum temperature is 75.5° in August, and the lowest is 69.4° in February. The average daily range is only 10.4°.

Southern Florida

That portion of Florida from Lake Okeechobee southward, although outside of the tropics, has a tropical rainy climate, which, however, fails in one particular to conform to the usual definition of lowland tropical climates. The region has occasional frosts and freezing temperatures. The rainfall conforms to the tropical rainy type, with a summer maximum and moderate winter amounts, and the average temperatures of all the months are above 65°, but the polar air from continental Canada which is responsible for the winter cold waves that sweep across the United States from the Great Plains to the Atlantic coast is occasionally carried southward to the southern tip of Florida. Miami has had a temperature of 27°. The great majority of the years pass without any frost, but at long intervals killing frosts extend to the extreme southern end of the mainland. None has ever been recorded at Key West. The summers are hot and humid with frequent thunderstorms, averaging thirty-five from June to September at Key West and fifty at Miami; the winters, especially along the Atlantic coast, are delight-

ful, making the coastal strip a favored winter resort. Population is concentrated at the coast. The interior largely consists of the Big Cypress Swamp on the west and the Everglades on the east, with their half-submerged islands luxuriantly clothed in tropical vegetation.

The Hawaiian Islands

This group of volcanic islands is situated in the trade winds of the north Pacific Ocean in practically the same latitude as the West Indies. They extend from northwest to southeast, and have central mountain ridges trending in the same general direction. They are, therefore, directly athwart the trades, which are here prevailingly from the northeast for most of the year (from the east from June to September, inclusive); hence the islands have a very wet windward side and a dry leeward side. Several higher stations on the windward side have more than 300 rainy days per year and more than 100 inches of rain; on the leeward sides the rainfall is moderate to light, and the number of rainy days is twenty-five to seventy-five.

Thermal convection is slight because of the small area of the islands, and the persistence of moderate breezes. There is a steady wind of about ten miles per hour, day and night, throughout the year. Thunderstorms are infrequent, averaging but five a year at Honolulu. The rainfall regime differs from that of the Gulf and Caribbean region in the small number of thunderstorms and in the fact that the rainfall is generally heaviest during the winter months. The latter is especially true on the leeward sides of the islands, because a cyclone from the Aleutian Low occasionally moves far enough south in winter to cause southerly winds. These are called *Kona* storms, and they bring heavy rains to the normally dry coasts. June and July are generally the driest months on both sides of the islands. Large variations in the annual amounts of rainfall in short distances, due to varying exposure and elevation, are characteristic.

There is no accumulation of warm water around the islands as there is in the confined Gulf and Caribbean regions, and the temperatures average somewhat lower than in the West Indies. This will be seen in the accompanying table in which Honolulu and Hilo are compared with Havana and San Juan. Hilo is on the wet side

of the Island of Hawaii, and Honolulu on the dry side of Oahu. The drier situations have an agreeable and healthful climate with moderate humidity and abundant sunshine. Some of the wetter localities are uncomfortably humid and deficient in sunshine. There is a wide variety of tropical vegetation on the islands. Sugar and pineapples are the principal exports.

MEAN TEMPERATURE

	Coolest Month	*Warmest Month*	*Year*	*Annual Rainfall (Inches)*
Honolulu	71.1	78.3	74.7	27.66
Hilo	69.2	74.8	72.1	139.43
Havana	71.6	82.4	77.4	48.22
San Juan	74.8	80.5	78.0	61.34

The three types of humid tropical climate are here found in close proximity. The windward slopes have a tropical rainy climate of the trade wind variety (TRt); the leeward sides have a tropical savanna climate (TS) with dry summers, and there are small plateaus above 4,000 feet where the climate is of a tropical highland character (TH).

Summary

The outstanding characteristic of the tropical climates is the uniformly high average temperature with little variation during the year. Daily ranges of temperature are small also, although normally greater than the annual ranges. Another prominent feature is the slight difference in temperature from place to place, except as affected by elevation. The tropical rainy regions of Central America and Mexico are hot, humid, debilitating, and rather unfavorable for human habitation, and malaria is common. Nevertheless, living conditions could doubtless be greatly improved, as they have been in the Canal Zone, by strict attention to drainage and sanitation. The heavy rain and the high temperatures throughout the year result in a native vegetation of the tropical jungle type. Important commercial crops are bananas, cacao, and coconuts.

The wet regions of the West Indies and the Territory of Hawaii have a less oppressive climate. They are mainly north of latitude 18° N., and they are subject to more regular and less humid trade winds, but the relative humidity is generally above 75% and the

day temperatures are between 80° and 90°. This is uncomfortable for active, outdoor labor where the air movement is slight, as in the sugar-cane fields; shaded situations open to the trade winds, however, are mild and pleasant. The tropical savannas of Central America have a dry winter season that is comfortable and pleasant. Similar regions in the West Indies and Hawaii are enjoyable and healthful, but are not stimulating.

Tropical Highlands of Central America and Mexico

A distinct type of climate (TH) prevails in the plateaus of Central America and Mexico and in tropical highlands in other parts of the world. It combines many of the characteristics of plateau climates and tropical climates. Because these areas are within or near the Tropics, they have days and nights of almost equal length at all times, two periods of vertical sun, and small seasonal changes in temperature. At elevations of 3,000 to 8,000 feet and removed from marine control, they heat rapidly by day and cool rapidly at night. This is true especially in the more level portions where air drainage and mixing are not active. The result is rather large daily ranges for low latitudes and occasional frosts at the higher elevations. In the Latin American countries this highland region is known as the *tierra templada* (temperate land), in contrast with the tropical lowlands (*tierra caliente*).

Temperature

The climate of the highland regions of Central America and Mexico is distinguished from the tropical rainy and savanna climates by the lower temperatures, and in particular because at least one month (usually several) has a mean temperature below 65°. Temperatures have about the same annual range as in the lowlands, but manifest a greater daily range. Compare, for example, the temperatures at Chimax bei Coban in central Guatemala (elevation 4,280 feet) and those at Mexico City (elevation 7,457 feet) with those at the tropical station at Salina Cruz, 184 feet above sea level on the Gulf of Tehuantepec (see Fig. 33). The annual march of temperature is much the same, temperatures rising to a maximum in late spring and remaining at nearly that level until the autumn equinox. We should expect a more pronounced tendency toward an autumn maximum, for in mountain climates in higher latitudes the time of maximum is usually de-

layed somewhat and the spring months are cool in comparison with lowland continental climates. In the case of these tropical highlands, however, it is evident that the retarding effect of elevation is offset by the cooling due to cloudiness and rain in late summer.

Although the temperature curves resemble those of the lowland stations, the general level of temperature is 13° to 18° lower at the highland stations. At Chimax bei Coban there are four months with average temperatures below 65°, and at Mexico City

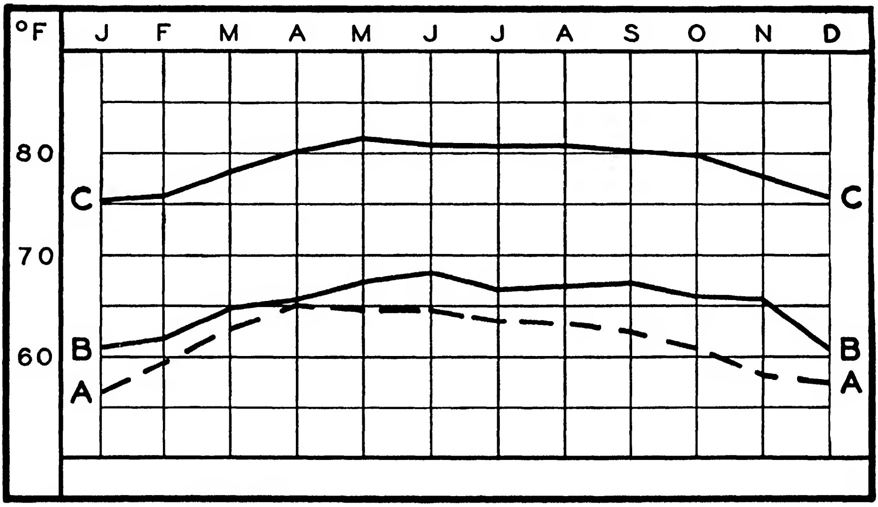

Fig. 33—Average Temperature. Tropical savanna and tropical highland climates of Mexico and Central America.

A. Mexico City (TH), Elevation 7,457 feet. B. Chimax, Guatemala (TH), Elevation 4,280 feet. C. Salina Cruz, Mexico (TS), Elevation 184 feet.

only the three months of April, May, and June have really tropical average temperatures. All months, however, even at the height of Mexico City, are well above the lower subtropical limit of 43°. Maximum temperatures are moderate. During the hottest part of the year the mean daily maximum at Mexico City is only 79°, and the mean daily minimum is about 57°. In January the mean maximum is 66°, the mean minimum 42°, and temperatures below freezing are not uncommon in December, January, and February. Temperatures are more largely governed by elevation than by latitude, but at the same elevation temperatures in the Central American plateaus are slightly higher than in the Mexican

plateau farther north. Throughout these highland areas the low-sun months are cool, clear, and, in the higher portions, even bracing. As is general in elevated regions, one is hot in the sun and comparatively cool in the shade. During the rainy season the humidity is high and the weather uncomfortable.

Rainfall

The tropical highlands of Central America and Mexico have a rainfall regime similar to that of the adjacent lowlands of the savanna type. There is a marked maximum from June to October, and, in the main, little rainfall during the cooler months. The total is generally less than in the lowlands, but some parts, especially interior Guatemala and the State of Chiapas, Mexico, bordering Guatemala, have very heavy rain, and considerable rain in all months. (See the record for Chimax bei Coban.) In most of the Central American plateau the rainfall is ample, but there are areas of light rain; very much depends on topography and exposure to prevailing winds. Where the prevailing movement of air is down-slope, the rainfall is light. In Honduras and Nicaragua the topography is quite irregular; there are basins virtually enclosed by hills or mountains which are desert-like.

On the plateaus of Mexico and Central America the surface becomes heated in summer, resulting in inflowing air mainly from the Gulf of Mexico, and in convectional rising, producing a moderate summer rainfall which occurs chiefly in the afternoon or evening in the form of thundershowers. The cooling of these plateaus in the winter months results in a tendency to out-flowing and down-flowing air and very little rain. The Mexican plateau is occasionally invaded by "northers" from the United States in winter, bringing a persistent drizzle to the north slopes. In Fig. 34 the rainfall in the Valley of Mexico is compared with that at Veracruz on the Gulf coast in about the same latitude. Note that the total on the plateau is only about one-third of the amount on the coast. This type of climate, with moderate rainfall (mostly twenty-five to forty inches) not only includes practically all that portion of the central plateau of Mexico south of latitude 21° N., but extends northward through Durango and the southern half of Chihuahua on the western side of the plateau—that is on the eastern slope of the Sierra Madre Occidental. Here the forced

ascent of the trade winds gives good summer rains, but the winters are dry. In considerable areas included in this climatic province the rainfall is rather insufficient for full use of the land, droughts are common, and irrigation is practiced. The rest of

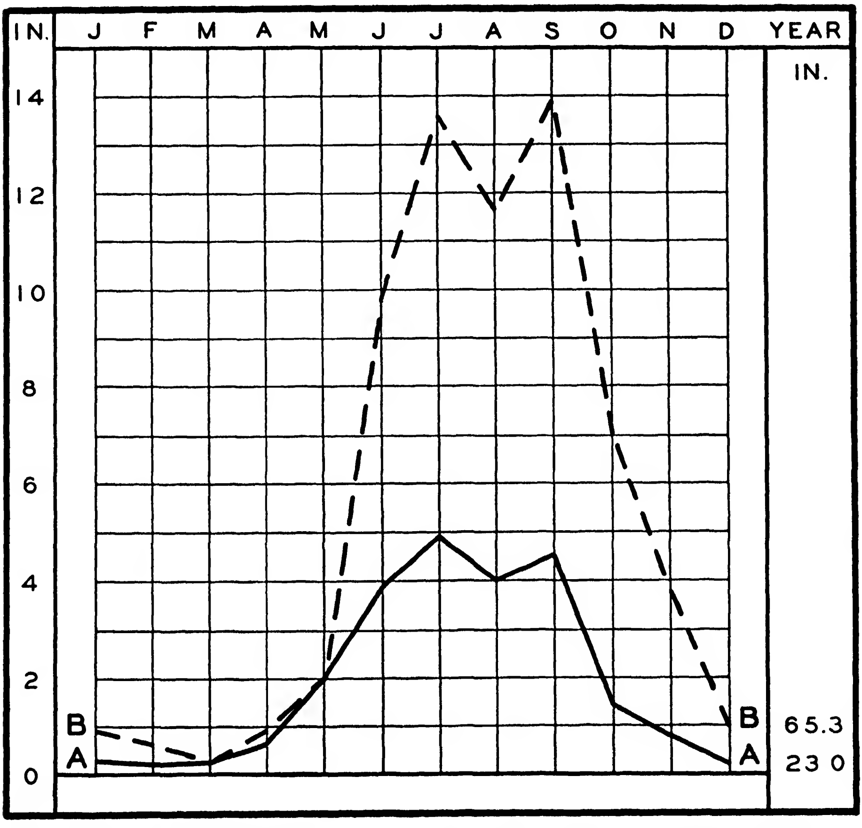

FIG. 34—Average Precipitation. Tropical savanna and tropical highland climates of Mexico.
A. Mexico City, Elevation 7,457 feet. B. Veracruz, Elevation 52 feet.

northern Mexico is included in the still drier climates which will be discussed later.

The predominantly greater portion of the population of Central America and Mexico lives in these elevated regions where the climate is more pleasant and more healthful than in the lowlands. The cooler and drier half of the year is particularly agreeable. Coffee is the typical crop of the tropical highlands, but in the lower portions of the highland region of Central America and

southern Mexico such tropical and subtropical crops as bananas, sugar cane, coconuts, cacao, and citrus fruits are produced. Coffee and bananas are the chief exports. In the higher portions the products are chiefly those characteristic of middle latitudes, such as corn, wheat, and beans, and there is much grazing land on which cattle and sheep are maintained.

CHAPTER XI

Dry Climates of North America

On their northern boundaries, the savannas and tropical highlands of Mexico become gradually drier and merge into the semiarid and arid lands of northern Mexico. This is the southern end of the great steppe and desert region of North America which extends from latitude 21° N. in Central Mexico to about latitude 54° N. in western Canada, with a longitudinal expanse from the 100th meridian westward to the Pacific coast of Mexico and to the Sierra Nevada and the Cascades of the United States and Canada.

Within this vast area, extending through 33° of latitude, there are of course great diversities of temperature conditions ranging from subtropical to cold continental. On the basis of the effectiveness of precipitation the area is divided into two main types of climate: the semiarid or steppe climates, and the arid or desert climates. A further division on the basis of temperature separates the warm steppes and deserts of tropical and subtropical latitudes from the middle latitude steppes and deserts. The warm areas have a mean annual temperature above 64°; the middle latitude areas have cold winters and an annual mean below 64°. Maximum temperatures during the hot season are similar throughout the region. In the classification used here the warm (low latitude) steppes and deserts are listed as having subtropical climates (STS and STD). They are often classified as tropical. In fact, they are neither typically tropical nor subtropical in the common usage of those words, but on the basis of temperature they appear to be more properly called *subtropical,* and in large part they are situated outside of the Tropics.

The boundaries between the humid climates and the steppe climates, and between steppe and desert, are more or less clearly marked by native vegetation. They were determined by Köppen as explained in Chapter VIII, not by total annual rainfall alone, but by the relations between temperature, precipitation, and the

annual distribution of precipitation. Insufficiency of precipitation is the outstanding feature of the dry climates; temperature differences are of minor importance. Hence, all deserts have a certain similarity of appearance, of native vegetation, and of human occupation. Likewise, all steppes are similar in these respects.

The Low Latitude Steppe Region of Mexico (STS)

At the southern end of the North American region of dry climates is a semiarid subtropical belt comprising portions of northeastern Mexico and a strip around the base of the western mountain range, the Sierra Madre Occidental. On the Gulf coast this belt extends from the Tropic of Cancer northward to the lower Rio Grande Valley, including a small portion of Texas, and inland to the central plateau. On the west it reaches to the Pacific coast for a short distance near the southern end of the Gulf of California. A small area on the northern coast of Yucatan is also included in this type. (See Fig. 28 and data for Mazatlan, Monterrey, and Brownsville.)

Temperature

The temperatures of this steppe region show the effect of the higher latitude and the lower humidity as compared with the tropical climates. This is evidenced in the greater annual range of temperature. Compare Fig. 35, showing the annual march of temperature at three cities in the steppe region, with Figs. 31, 32, and 33 for the humid tropical climates. The temperatures of the hottest months are nearly the same in the two regions and the greater ranges in the steppe region are owing to the cooler weather there during the low-sun months. This is especially true at Brownsville, which is on the coast but at the northerly edge of the region, and at Monterrey, which is 180 miles inland at an elevation of about 1,700 feet. The annual range at these stations is 24°–25° and at Mazatlan, 14°, as compared with ranges of 3°–12° in the humid tropical lowlands.

Comparing Monterrey and Mexico City, which are about equally distant from the coast, one representing the steppe and the other the highlands, it will be noted that the temperatures of the coldest months (December and January) are approximately the same: the greater elevation of Mexico City offsets the effect of

the higher latitude of Monterrey. In summer the highland climate remains cool, but Monterrey and Brownsville heat rapidly in spring and have three months (June, July, and August) of tropical temperatures, with minimum temperatures above 70° and maxima occasionally slightly above 100°. The Pacific coast portion of the region has tropical temperature conditions throughout the year. In the remainder of the region there are three or four winter months with mean temperatures below 65° and occasional frosts. Freezing temperatures occur an average of three

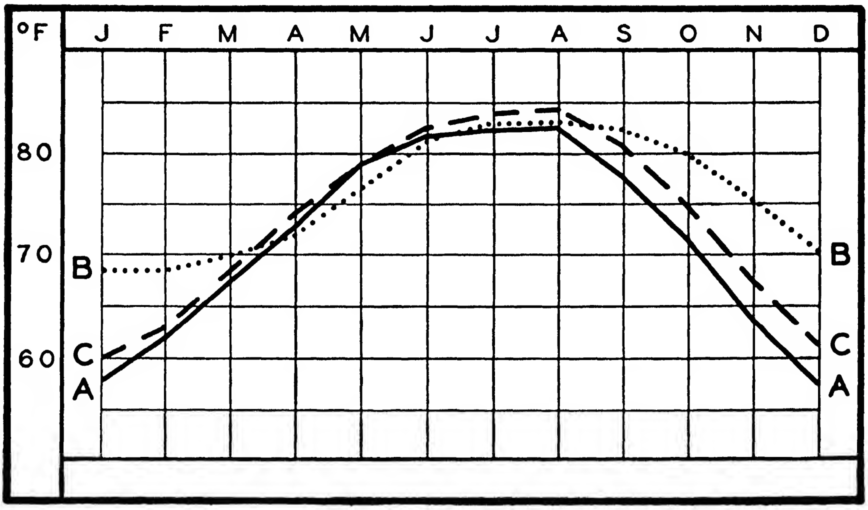

FIG. 35.—Average Temperature. Low-latitude steppe climate of Mexico. (Compare with Figs. 31, 32, and 33.)
A. Monterrey, Mexico. B. Mazatlan, Mexico. C. Brownsville, Texas.

days a year at Brownsville. A feature of the climate of the eastern portion of the region is the occasional occurrence in winter of relatively cold "northers" composed of polar continental air from the United States. These occur from November to March, and they sometimes cause a drop of 40° in the temperature along the Gulf coast.

Rainfall

The rainfall of the region averages from twenty to twenty-five inches a year, but there are great local diversities governed by exposure and elevation. The yearly variability is also very great. At Brownsville the annual amounts have varied from 12.15 inches

to 60.06 inches, and every month except September has at one time or another passed without any measurable rainfall. Reference to Fig. 36 indicates that the year is dry except for a brief rainy period in summer. In the areas sloping toward the Gulf of Mexico there is a maximum in September and a secondary maxi-

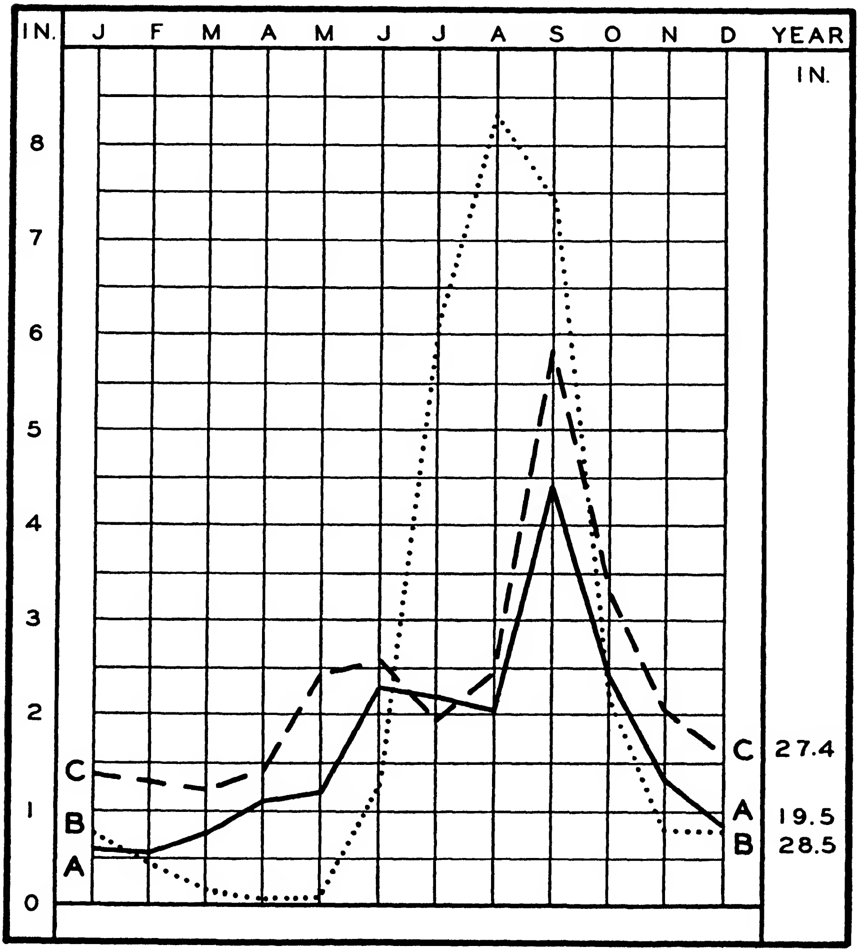

FIG. 36.—Average Precipitation. Low-latitude steppe climate of Mexico. A. Monterrey, Mexico. B. Mazatlan, Mexico. C. Brownsville, Texas.

mum, with about half the September total, in June. On the Pacific slope (Mazatlan) February to May is almost rainless, and often the individual months are entirely so, but rainfall is rather heavy in July, August, and September. These three months receive three-fourths of the total annual rainfall.

Steppes and Deserts of Mexico and United States	Mean Temperature °F.				Average Precip. In.			Snow-fall Inches	Rel. Hum. %	Sun-shine %	Number of Days			
	Year	Cool-est Month	Warm-est Month	Range	Year	Wet-test Month	Driest Month				.01 in. or more	90° or above	32° or below	Grow-ing Season
STS														
Mazatlan, Mex.	75.9	Feb. 68.5	Aug. 82.9	14.4	28 45	Aug. 8.34	Apr. 0.06	. .	. .	. .	. .	. . .	. .	. . .
Monterrey, Mex.	71.4	Dec. 57.4	Aug. 82.6	25.2	19.54	Sept. 4.42	Feb. 0.56	. .	. .	. .	. .	. . .	. . .	. . .
Brownsville, Tex.	73.2	Jan. 59.5	Aug. 84 0	24.5	27 24	Sept. 5 67	March 1 20	T	82	62	73	110	3	332
STD														
Hermosilla, Mex.	75.4	Dec. 61.9	July 88.2	26.3	. . . .	. . . .	. . . .	. .	. .	. .	. .	.	. . .	. . .
El Paso. Tex.	63.6	Jan. 44.9	July 81.6	36.7	8 86	July 1.85	April 0.23	2	41	80	51	84	47	241
Phoenix, Ariz.	69.5	Jan. 50.9	July 89.7	38.8	7.43	July 1.01	June 0.08	T	42	84	39	148	12	296
Palm Springs, Calif.	72.7	Dec. 54 9	July 92.7	37.8	4 80	Feb. 1.20	June T		. .	. .	. .	. .	. . .	. . .
Needles, Calif.	71.9	Jan. 51.7	July 94.0	42.3	4.45	Aug. 0.74	June 0.06	. .	. .	. .	17	. .	. . .	301
Greenland Ranch, Calif.	75.3	Jan. 51.4	July 102.0	50 6	1.45	Jan. 0 33	June 0.03	. .	. .	. .	.	. . .	. . .	. . .
ID														
Modena, Utah	47.7	Jan. 26.8	July 70.8	44.0	11.01	Aug. 1.57	June 0 36	32	52	74	66	19	178	131
Tonopah, Nev.	50 4	Jan. 30.4	July 73.7	43 3	4.83	Aug. 0.58	June 0 20	23	45	76	36	. . .	. . .	147
Reno, Nev.	49 8	Jan. 31 6	July 70.1	38.5	7.14	Jan. 1.48	Aug. 0 20	31	52	74	50	25	149	145

T = Trace.

The summer rains are due to moist inflowing, monsoonal winds moving up-slope, aided by convectional rising over the heated interior. In the winter the cooler interior tends to produce descending air, but on the Gulf slope the trade winds bring inflowing air and light rain, and in the Rio Grande Valley extratropical cyclones moving across Texas produce occasional winter rains. On the Pacific slope the winds in winter are almost continuously downward and off-shore, and they are therefore dry. The relative humidity, about 70% throughout the year in the eastern portion of the region, is unusually high for so dry a region. It is kept high in the interior in winter by the low temperatures and in summer by the indraft of moist air from the Gulf of Mexico. On the west coast humidity is high in August and September, but low in the spring.

Since the rainfall occurs largely during the hot part of the year, and since the dry season is moderately cool, the moisture is sufficient to maintain a cover of short grasses which supports a considerable number of cattle, sheep, and goats. In the wetter areas the moisture is sufficient for the production of wheat and corn, but, because of the large variability of the rainfall, these crops are subject to rather frequent injury by drought. Under irrigation citrus fruits and truck crops are grown extensively in the lower Rio Grande Valley in the Texas portion of this climatic province.

The Desert Areas of North America

Northward from the semiarid region just described, the rainfall gets lighter and the warm steppe merges into a great desert region which extends in places from northern Mexico to southeastern Washington, as shown in Fig. 28. On the east the arid portion includes the north portion of the central plateau of Mexico, extreme southwestern Texas along the Rio Grande, and a strip across southern New Mexico and southern Arizona. On the west it includes Baja California and the western portion of Sonora on the eastern side of the Gulf of California, and from this region it extends into the United States to embrace the great desert region of southeastern California, nearly all of Nevada, some portions of Utah, and isolated areas in Oregon and Washington.

Reasons for aridity

The northern part of this region is in the "rain shadow" of high mountain systems. The Cascades and the Sierra Nevada—the latter merging into the Coast Range in southern California—intercept the moisture from the Pacific; the result is dry descending air on their eastern slopes. The Rocky Mountains prevent the arrival of much moisture from the east. In winter the high pressure that develops over the Great Basin is an additional obstacle to much precipitation.

The southern portion of this dry-climate area, from southern California to Texas and southward into Mexico, is in the subtropical belt of high pressure, which is characteristically dry around the world. In winter, the winds are from north or northwest out of the Great Basin center of high pressure, and they decrease in humidity as they move southward to warmer latitudes. In summer the inflowing winds on the Pacific side pass over the abnormally cool water along the California and Lower California coasts, and hence are dry as they move inland over the very warm land surface. For these various reasons the lower Colorado River Basin is the driest portion of the Continent. In the eastern portion of the dry belt, from Texas to Arizona, there are easterly winds in summer flowing toward the Arizona center of low pressure, but their humidity is usually low because of the heated surfaces over which they move. However, there are places here that receive some good rains during July, August, and September.

Low latitude desert region (STD)

The subtropical desert region of Mexico and the United States may be divided into two parts—a western portion of extreme heat and aridity and an eastern portion where desert conditions are somewhat less severe. In the western region the desert extends northward into middle latitudes, and the low latitude desert merges into an intermediate desert (ID). The eastern region merges on the north into a middle latitude steppe (IS).

Western desert region

Extreme desert conditions prevail in Baja California, northwestern Sonora, southeastern California east of the Coast Range,

and southwestern Arizona in the lower Gila River Valley. Within this region are the Colorado and Mojave Deserts, the Imperial Valley, and Death Valley, along the California-Nevada line. The northwestern part of the California desert area, including Owens

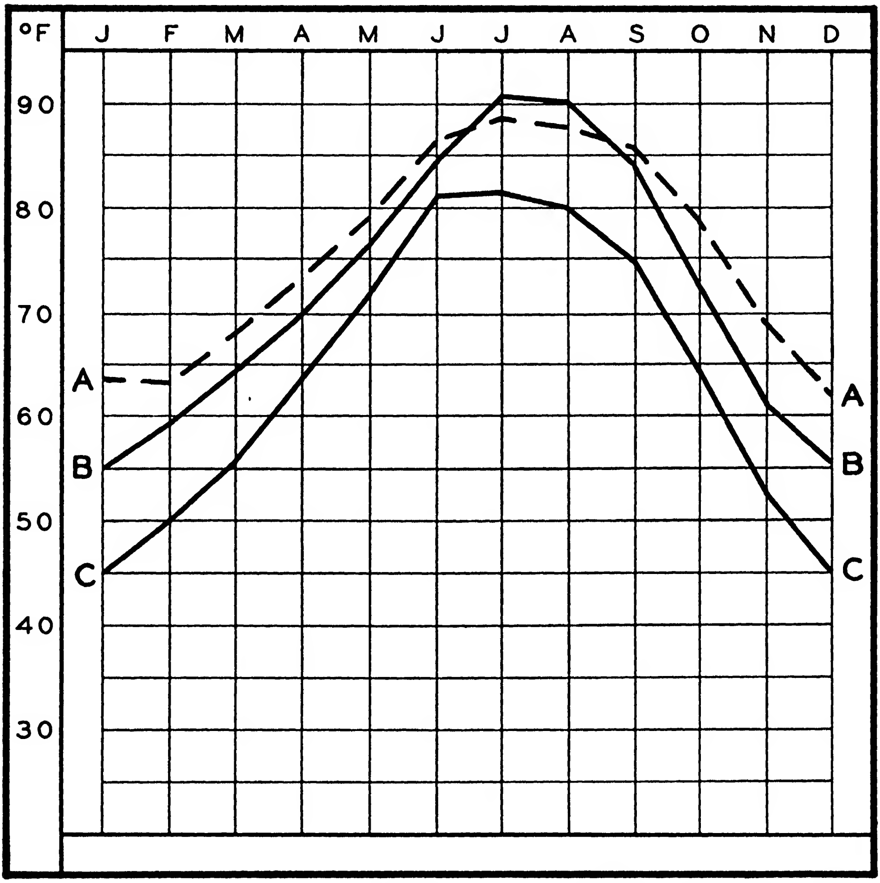

Fig. 37—Average Temperature. Low-latitude desert of Mexico and United States. A. Hermosillo. B. Yuma. C. El Paso.

Valley and the western portion of the Mojave Desert, has cold winters and belongs in the intermediate desert region.

The Mojave Desert is a wide and level waste of sand. In the Colorado Desert there are areas of shifting, yellow sand dunes where there is an almost complete absence of vegetation. The Imperial Valley is generally level and bare, and much of it is below sea-level. In these deserts summer days are extremely hot

and dry. Maximum temperatures are above 100° almost daily in midsummer and are of frequent occurrence from May to September, inclusive. Because of the rapid radiational cooling in the dry air, temperatures fall rapidly during the night both in summer and in winter. In winter there is, in addition, some inflowing of cold air from the north. The winters are thus surprisingly cool and frosts are common, but the rapid warming by day keeps daily mean temperatures above 50° throughout the year.

Conditions at Yuma (see Fig. 37) are typical of a considerable area in the Colorado Desert and the Imperial Valley. The average temperature is 91° in July and 54° in January, an annual

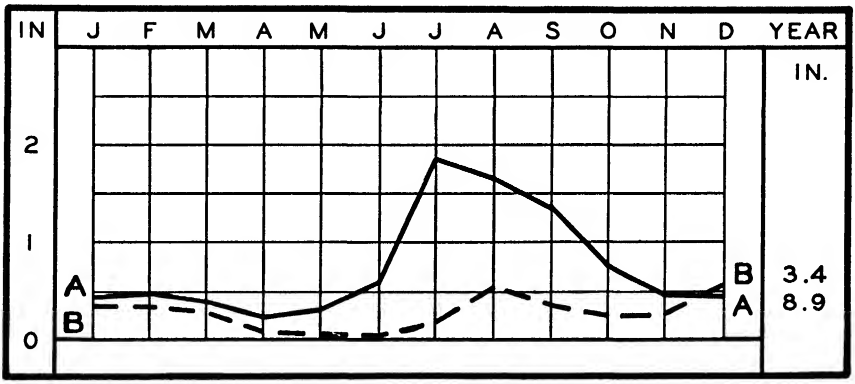

Fig. 38—Average Precipitation. Low-latitude desert of the United States.
A. El Paso. B. Yuma.

range of 37°. The mean daily maximum is above 100° in June, July, and August. The mean daily minimum is 77° in July and 42° in January. Frosts occur in most years, and freezing temperatures have been observed from November to March, inclusive, but the average length of the growing season is 349 days. The rainfall is of little significance, as is indicated in Fig. 38. The average annual amount is only 3.38 inches, and only two months, August and December, have as much as half an inch. In 1928 only 0.47 inch fell during the year; in 1905 there was a total of 11.41 inches.

Such winter rain as falls results from the infrequent occurrence of cyclones in the Gulf of California region. The summer rain is in the form of sporadic thundershowers. There is an average of sixteen rainy days a year at Yuma, and sunshine is 90% of the

possible amount. This is in the zone of maximum sunshine in the United States. The average relative humidity is 44%, ranging from 37% in April, May, and June, to 49% in August. At Greenland Ranch, Death Valley, the average annual precipitation is 1.45 inches, and the entire year 1929 passed without any rain. It is here that a temperature of 134°, the highest of record in the United States, was recorded under standard Weather Bureau conditions. In its natural state the region is almost devoid of vegetation, although in places there are giant cacti and small desert trees (acacias and palo-verdes). Under irrigation from the Colorado River, the Imperial Valley produces warm-climate crops such as cotton, olives, citrus fruits, dates, and winter vegetables abundantly. The soil is a silt deposited by the Colorado River, and is said to be 1,800 feet deep.

Eastern desert region

The eastern portion of the arid region comprises the northern plateau of Mexico and adjacent portions of Arizona, New Mexico, and southwest Texas. Here, where much of the region has an elevation of 3,000 to 5,000 feet, the desert conditions are less extreme. As compared with the western desert areas, both summer and winter temperatures are somewhat lower, daily and annual ranges of temperature are similar, and the rainfall (although generally less than ten inches) is somewhat greater. Instead of being a barren waste, the landscape includes a nearly continuous covering of plants and bushes, such as mesquite, greasewood, creosote bush, yucca, and numerous species of cactus. Grasses spring up rapidly after a rain, and in many places there is sufficient herbage to support a small number of cattle on range. Along the Rio Grande and the small streams that enter the region, the irrigated bottom lands are dark green with broad-leaved trees, alfalfa, cotton, and other crops, in contrast with the dusty grayish green of the desert vegetation outside of the irrigated acreage.

Temperature conditions in this area are represented by El Paso (Fig. 37). The annual march is much the same as in Yuma, but temperatures average about 8.5° lower. The difference is only 4° in June but more than 10° in December and January, and these two months have an average temperature of 45°. Freezing temperatures have been recorded in all months from October to April, inclusive. The reason for the relatively cold winters is to be found

partly in the elevation and partly in the fact that this region east of the mountains is open to the invasion of cold "northers." These occur when polar continental air swings far southward in its course across North America, in the rear of a well-developed cyclonic area moving across the southern portion of the United States. This northern air is responsible especially for the occasional hard freezes that occur. Maximum temperatures above 100° are of common occurrence in June, July, and August, but the average daily maximum of these months is 8° to 13° less at El Paso than at Yuma. The average maximum is highest in June because of the greater afternoon cloudiness and rainfall during July and August.

Most of the rain falls during July, August, and September—largely in the form of afternoon thundershowers. Such winter rain as occurs—less than half an inch per month from November to May—is in connection with the movement of cyclonic storms whose centers are generally north of the region. Many years have a period of at least a month without rain, and occasionally there are two rainless months in succession. Annual totals at El Paso have varied between 2.22 and 21.81 inches. Rain falls an average of fifty-one days a year, but sunshine averages 80% of the possible, and relative humidity is only 41%, which is slightly less than at Yuma. (See, also, data for Phoenix, page 171.)

The Great Basin Desert (ID)

From the subtropical desert of the lower Colorado River Valley, desert conditions, not quite so intense, extend northward and cover nearly all of Nevada, portions of eastern California, and parts of Utah, Oregon, and Washington. This region corresponds roughly to the physiographic division known as the *Great Basin*, but includes portions of the *Columbia Plateau*. These areas are middle latitude deserts of pronounced continental temperature characteristics. (See data, page 171.) Annual ranges are from 38° to 48°, increasing northward. But the temperature differences are of minor importance; the deficiency of moisture gives to all parts of the region an essential similarity of climate and of general character. With the change in temperature, there is, however, some change in the characteristic vegetation, the cactus and creosote bush of the south giving place to vast fields of grayish-green sagebrush.

Mean monthly temperatures at three representative stations are shown in Fig. 39. At Independence, the warmest of the three, all months average above freezing, but mean minimum temperatures are below freezing for three months. Late spring frosts are

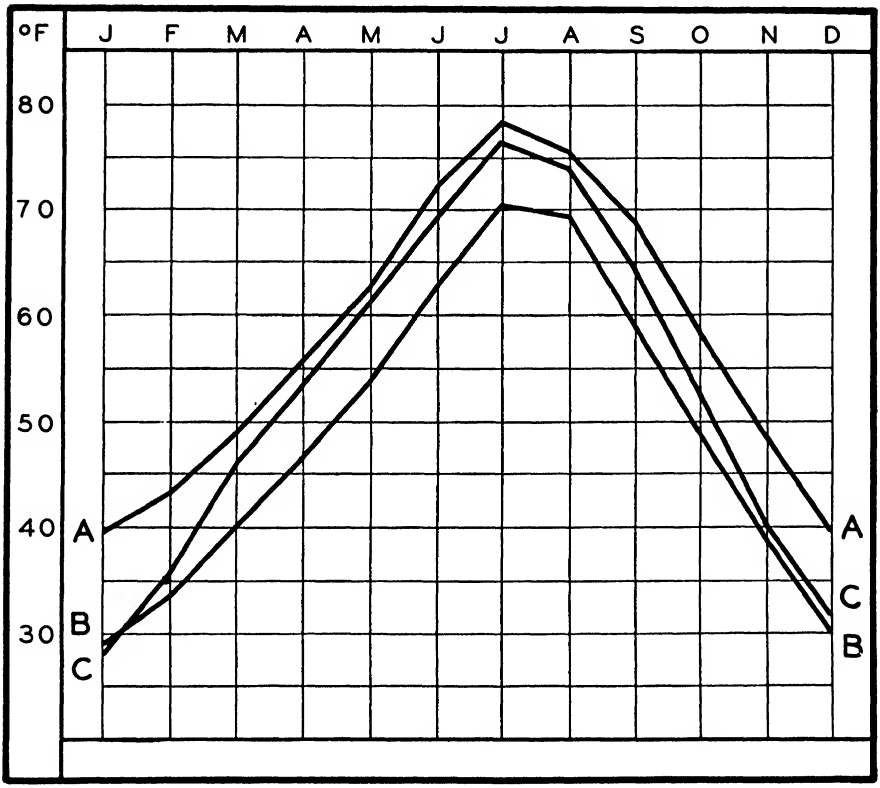

FIG. 39—Average Temperature. Great Basin desert (ID) of the United States. A. Independence, California. B. Winnemucca, Nevada. C. Hanford, Washington.

frequent, and the growing season is about 6.5 months in length. It will be noted that Hanford, Washington, although about 5.5° of latitude north of Winnemucca, has approximately the same winter temperatures and considerably higher spring and summer temperatures. This is partly due to the lesser elevation of Hanford, but summer temperatures are also influenced by the fact that it is in a smaller, more inclosed basin, and that it has more summer sunshine. Hanford has an average of 182 days between the killing frosts of spring and autumn, and Winnemucca, 136 days. In most of the Great Basin and in the Columbia Plateau, December and

January have average temperatures below freezing, zero temperatures are of frequent occurrence, and temperatures of —20° or lower occur occasionally.

Precipitation in these areas amounts to four to ten inches a year in general, but is more than ten inches on the eastern slope of the Sierra Nevada Mountains in western Nevada. The average annual precipitation for the entire state of Nevada is about nine inches. The greater amounts fall in the winter months, as is indicated in Fig. 40, and July and August are either rainless or almost

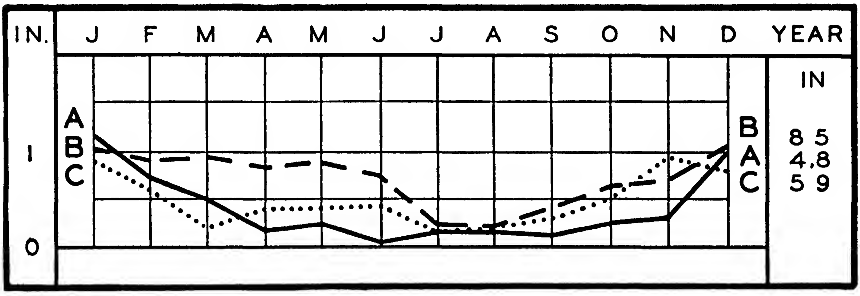

FIG. 40—Average Precipitation. Great Basin desert (ID) of the United States. A. Independence, California. B. Winnemucca, Nevada. C. Hanford, Washington.

rainless. The winter rainfall results from the passage of cyclonic areas eastward from the Pacific Ocean, and is mostly in the form of snow in Nevada and the Columbia Plateau; the amounts range from fifteen to fifty inches. In summer there is an occasional local shower, sometimes heavy over a small area. Sunshine is 83% of possible at Independence, 74% at Winnemucca, and about 60% in the portions of Oregon and Washington under consideration; during the summer months sunshine is generally above 80%.

The Intermountain Steppe Region (IS)

The remainder of the intermountain region, lying between the Sierra Nevada and the Cascades on the west and the Rocky Mountains on the east, is a semiarid plateau ranging chiefly between 2,000 and 8,000 feet in elevation. It has a middle latitude steppe climate, but is much broken up by small mountain systems and detached ridges. These mountains and ridges are separated by plains and valleys, and this diverse topography gives rise to many local variations in climate. It is, however, a dry region through-

out, except on some of the higher slopes, and it has rather high summer temperatures and moderately cold winters. Maximum temperatures occasionally exceed 100°, and minima fall below — 20°. Data for several stations are given on page 181.

Northern Arizona and northwestern New Mexico have a number of river valleys and undulating plains that receive from ten to eighteen inches of rain, 60% of which falls during July, August, and the first half of September. This rain is of the convectional type, from a moist air mass moving in from the south, and it is sufficient in places for the production of cereal grains by dry farming methods. May and June, and often April, are very dry, however, and spring irrigation is necessary for the production of potatoes and fruits.

In Utah the elevation ranges from 2,500 feet to more than 6,000 feet, and the mean annual temperature varies from 59° for places under 4,000 feet, to 44° for elevations over 6,000 feet, corresponding approximately to the mean annual temperatures at Oklahoma City and Minneapolis, respectively. The growing season is about six months in length and many of the valleys are well adapted to the growing of alfalfa and deciduous fruits under irrigation.

The rainfall regime is almost the reverse of that in Arizona. The maximum occurs in March, April, and May, and is cyclonic in origin. Cyclones from the Pacific Ocean invade this area more frequently in spring than in winter because of the winter high pressure area centered in this vicinity. The influence of these storms does not often extend into Arizona. June, July, and August constitute the dry season. During these months hot, dry, continental air overlies the state; the moist air that gives Arizona its summer showers turns eastward instead of extending northward into Utah. The annual precipitation averages about ten inches at the lower stations and about fifteen inches in the more elevated regions. Humidity is moderate in winter and low in summer, and sunshine is about 70% of possible.

Idaho and western Montana are generally rugged, evincing great ranges in elevation and corresponding variations in climate. They are mostly between 3,000 and 5,000 feet in elevation, and most of the area has a mountain climate. Altitude influences both temperature and precipitation, the latter usually increasing with

Middle Latitute Steppes (IS) of U. S. and Canada	*Mean Temperature °F.*				*Average Precip. In.*			*Snow-fall in.*	*Rel. Hum. %*	*Sun-shine %*	*Number of Days*			
	Year	*Cool-est Month*	*Warm-est Month*	*Range*	*Year*	*Wet-test Month*	*Driest Month*				*.01 in. or more*	*90° or above*	*32° or below*	*Grow-ing season*
Intermountain Region Flagstaff, Ariz.	45 5	Jan. 27.6	July 65 3	37 7	21.92	July 3 12	June 0.45	78	60	79	84	1—	206	119
Pocatello, Ida.	47.7	Jan. 25 7	July 71 7	46 0	13 81	May 1.55	July 0 76	44	58	62	100	19	131	160
Baker, Ore.	45 5	Jan. 24 9	July 66 5	41 6	11.73	May 1 39	July 0 50	40	62	59	101	12	159	138
Missoula, Mont.	44 3	Jan. 21 7	July 67 4	45.7	15 21	June 2 08	Feb. 0 86	37	..	..	95	...	..	124
Walla Walla, Wash.	53 5	Jan. 32 4	July 75 0	42 6	16 66	Nov. 1 98	July 0 39	24	62	56	106	34	68	218
Great Plains Abilene, Tex.	64.2	Jan. 44 4	July 82 8	38.4	24.37	May 3 97	Jan. 0 89	4	62	..	67	86	44	232
Dodge City, Kan.	54 2	Jan. 29 3	July 77 9	48 6	20 51	June 3 24	Jan. 0 39	19	66	71	75	53	126	174
Cheyenne, Wyo.	44.6	Jan. 25 8	July 66.8	41 0	14 59	May 2 41	Jan. 0 39	55	58	66	94	5	173	127
Rapid City, S. D.	46.2	Jan. 22 5	July 71.0	48 5	18 11	May 3 48	Dec. 0 39	34	61	64	98	18	157	151
Williston, N. D.	39.6	Jan. 6 8	July 68.7	61.9	14 80	June 3 43	Feb. 0 41	33	70	59	91	15	186	130
Medicine Hat, Alb.	41.6	Jan. 11.3	July 67.9	56 6	13.03	June 2.64	Jan. 0.58	31	..	..	78	....	...	...

altitude. There is also a general increase in precipitation from west to east. There is some marine influence from the Pacific, and the climate is milder than the latitude and altitude would lead one to expect. It is milder than the climate in similar situations on the eastern slope of the Rockies because the Continental Divide

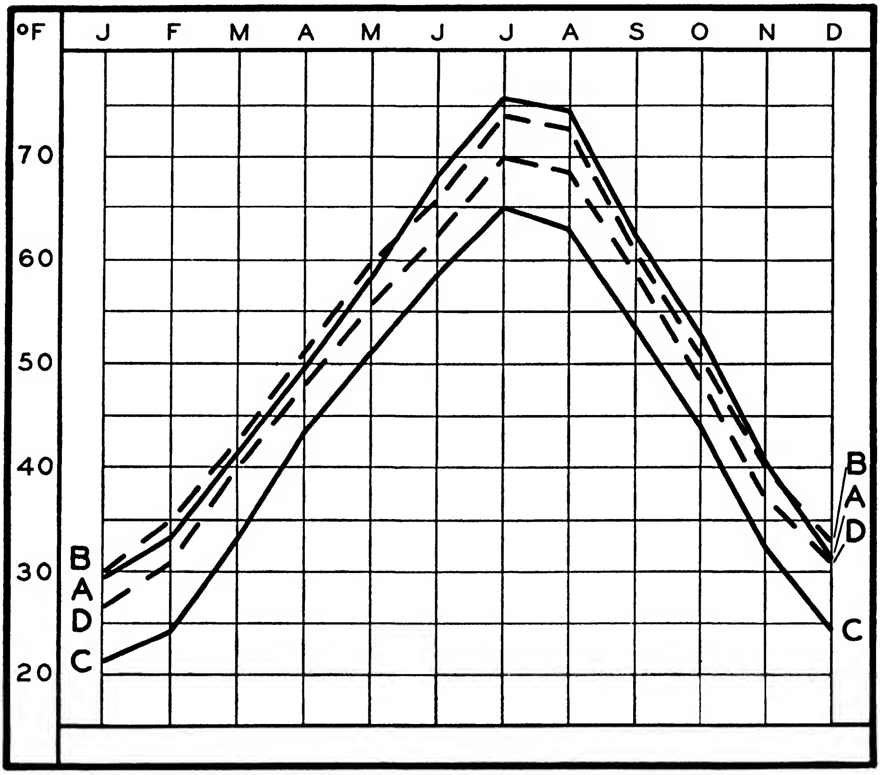

FIG. 41—Average Temperature. Intermountain steppe region (IS) of U. S.
A. Salt Lake City, Utah. C. Kalispell, Montana.
B. Boise, Idaho. D. Spokane, Washington.

acts as a barrier to cold Canadian air. The average winter temperature of southern Idaho is about equal to that of Illinois or Indiana, but the summer temperatures are more like those of North Dakota or northern New York.

Idaho's precipitation varies from less than ten inches to twenty-five inches, with a maximum in winter from traveling cyclones, and a minimum in July and August. There is much grazing land and some dry farming, and the irrigated valleys produce potatoes, sugar beets, and alfalfa. In western Montana the rain-

fall averages nearly twenty inches and is well distributed through the year.

In eastern Oregon and Washington temperatures are similar to those farther south, but they average slightly lower at all seasons than in Utah and southern Idaho. The striking similarity of the march of temperature throughout the intermountain steppe region is shown in Fig. 41. There are two or three months of moderately

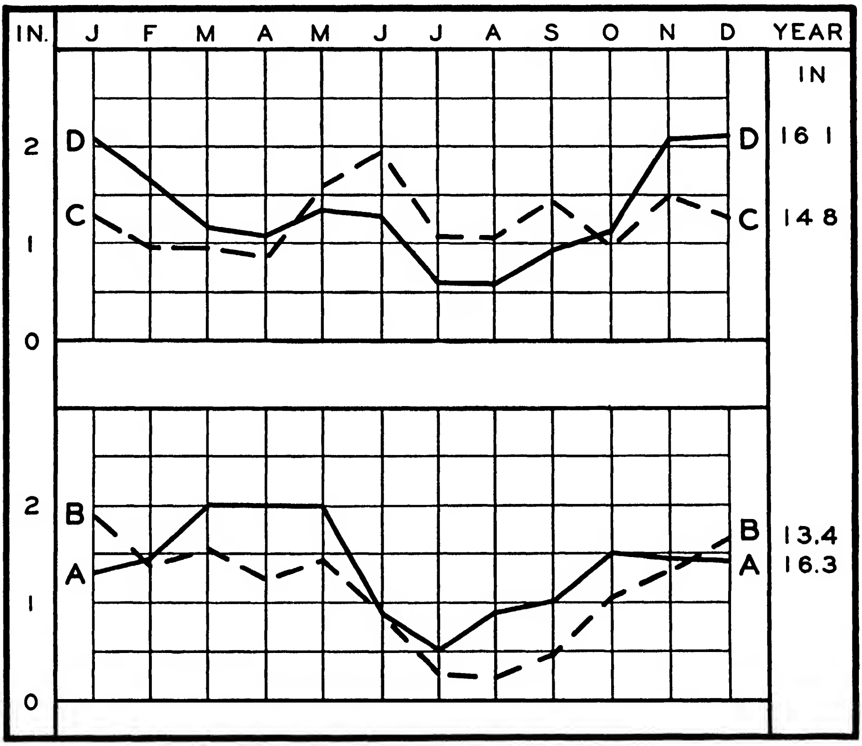

Fig. 42—Average Precipitation. Intermountain steppe region (IS) of U. S.
A. Salt Lake City, Utah. C. Kalispell, Montana.
B. Boise, Idaho. D. Spokane, Washington.

cold weather (December, January, and February), a rapid increase of temperature in spring, two hot months (July and August), and then a rapid decline to December. Precipitation (see Fig. 42) averages ten to twenty inches, with a maximum in winter of cyclonic origin, and a secondary maximum in May and June resulting from occasional thunderstorms accompanying the breaking up of heat waves. July, August, and September are the dry months, as in Idaho. The winter months have a rather high hu-

midity and 30% to 40% of possible sunshine; the summers are dry and sunny. This is an extensive wheat-raising region for which the rainfall distribution is very favorable. The May and June rains make the crop, and the dry weather that follows is favorable for ripening the grain and harvesting it.

The Great Plains (IS)

From the Panhandle of Texas northward into southern Canada, and from about the 100th meridian westward to the Rocky Mountains, stretches a large grassy, treeless plain, "the interminable prairie," sloping gently toward the Missouri and Mississippi Rivers. It is the typical steppe region of North America, and is similar to vast areas in Asia and southeastern Europe to which the name *steppe* was first applied. At the base of the mountains rolling plains begin at an elevation of about 6,000 feet; on their eastern border the plains are about 2,000 feet above sea level. A high percentage of sunshine and a rather low relative humidity prevail in all the area.

Temperature

Temperatures in this great area range from almost subtropical on the southern border to cold continental, but the difference is mainly in the colder months; high temperatures in summer are characteristic of the entire region. The mean July temperatures vary from about 80° in Texas to 60° in Canada, a difference of only 20°, and maxima above 100° have occurred in most of the area—in Canada as well as in Texas. There is little change in relative humidity from south to north; the air is dry in the entire region. Insolation penetrates this dry air freely, and almost equal amounts of insolation are received throughout the region during mid-summer, for, as the latitude increases, the decreasing elevation of the sun is balanced by the increasing length of the day. The result is that summer maximum temperatures in Montana and North Dakota equal those in western Texas.

Conditions are markedly different in winter. Mean January temperatures vary from 50° in the Texas plains to —5° in central Saskatchewan and Alberta, a difference of 55° as compared to the summer difference of 20°. Annual ranges increase accordingly from 30° in the south to 65° in the north. The great contrast be-

tween north and south is partly due to the usual latitudinal factors (short winter days and low sun in the higher latitudes), but it is more largely caused in this case by the greater frequency in the

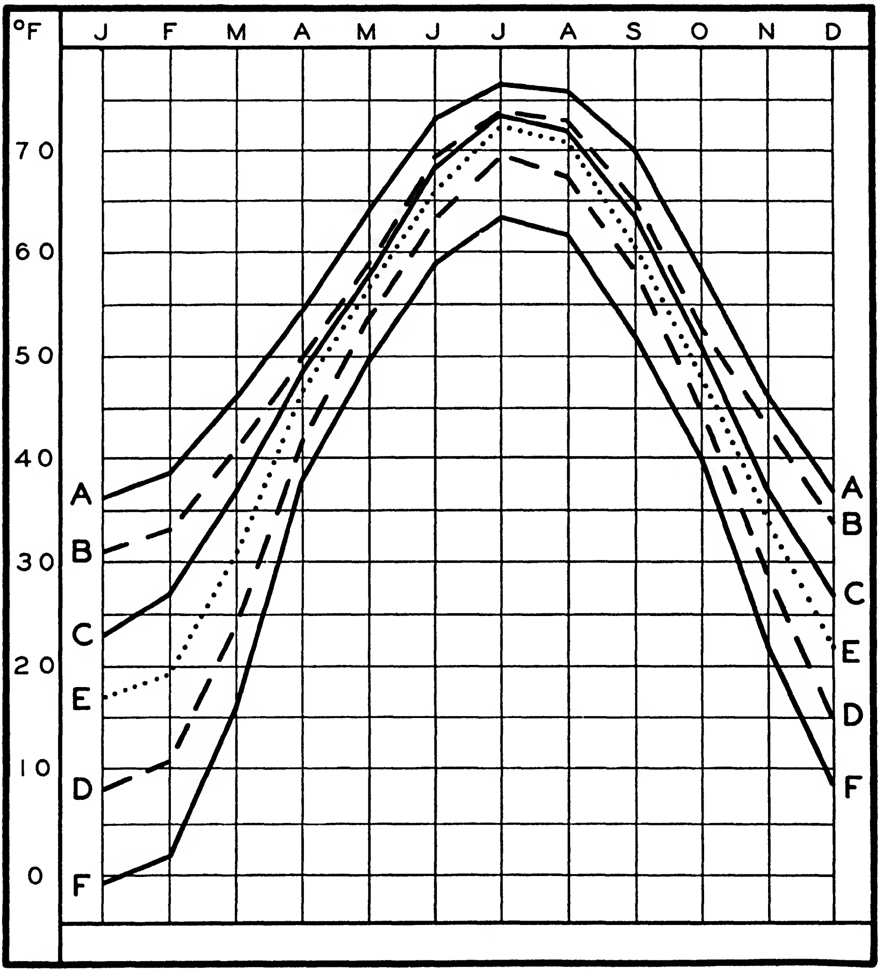

Fig. 43—Average Temperature. Great Plains (IS) of North America.
A. Amarillo, Texas. C. North Platte, Nebraska. E. Miles City, Montana.
B. Pueblo, Colorado. D. Bismarck, North Dakota. F. Qu'Appelle, Saskatchewan.

northern portions of the region of polar continental air masses from the Mackenzie Valley. Waves of cold polar air do occasionally overspread Texas and even parts of Mexico, as we have seen, but they are much more frequent in the northern plains. They are, moreover, much more severe in the north because the tem-

perature of the air which has traveled so far from its source is considerably moderated by the time it reaches the southern plains.

Tropical air attended by mild thawing weather in winter is frequently carried even to the northern border of this region with the eastward or northeastward movement of cyclones across the country. The sudden displacement of this warm moist air by dry, cold, polar air produces the sudden drop in temperature of 20° or more known as a *cold wave.* Sometimes the change occurs with strong northwest winds and driving snow, constituting what is called a *blizzard,* and necessitating the rounding up and protection of cattle and sheep on ranges. Cold waves occur more frequently in the northern half of the Great Plains than in the southern half and more frequently near their eastern border than near the Rocky Mountains. For this reason, and also because they are frequently warmed by *chinooks,* areas at the base of the mountains are somewhat warmer in winter than places in the same latitude farther east. Chinooks—warm, dry, descending winds which have crossed the mountains (see *foehn winds,* page 80)—cause a marked rise in temperature in winter and a rapid melting of the snow. In places they are frequent enough to modify the climate considerably.

The coldest winters in the United States are in northern North Dakota and northern Minnesota, where January temperatures average from 5° to zero. Zero temperatures occur about once in two years in the Texas Panhandle, and temperatures of —40° are of frequent occurrence in Saskatchewan and Alberta. The average length of the growing season decreases from about six and one-half months in western Texas to about three months in central Alberta and Saskatchewan. In Fig. 43 note the large annual range of temperature at all stations, but particularly the more northerly ones, where there is a rapid rise in spring to a short summer, and a rapid fall beginning in September. The July difference between Amarillo and Qu'Appelle is 13°; the January difference is 37°. Miles City, despite its greater elevation, is warmer than Bismarck in all months, because it is less frequently in the southward sweep of polar air.

Rainfall

The basis for placing this extensive region in one climatic type is chiefly the similarity in the amount and distribution of the rain-

fall. A secondary basis may be found in the similarity of summer temperatures and in the annual march of temperature. The rainfall increases from west to east, but varies little from north to south. Reference to Fig. 27 shows that the isohyets follow the meridians approximately. Within the immediate shadow of the Rockies, in Colorado, Wyoming, Montana, and Alberta, rainfall averages from ten to fifteen inches per year; eastward to approximately the 100th meridian, the amount is fifteen to twenty inches, all the way from Texas to Canada. But it should be noted that the effectiveness of the rainfall increases northward with decreas-

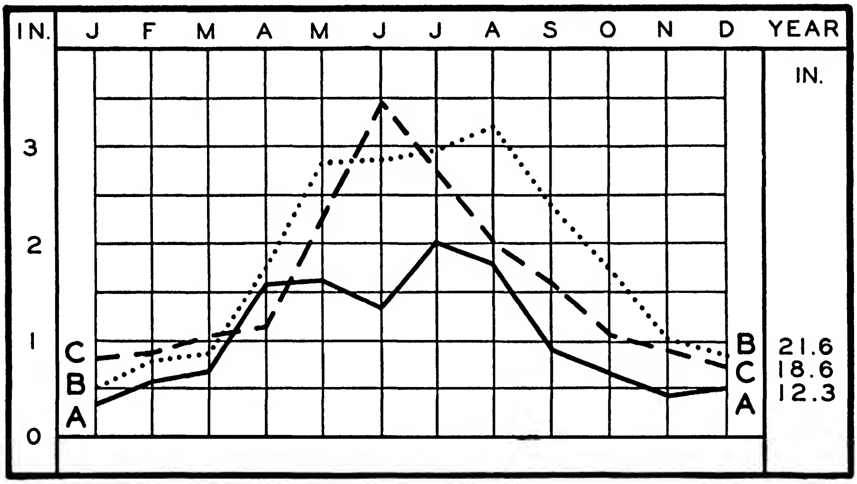

FIG. 44—Average Precipitation. Great Plains (IS) of North America.
A. Pueblo, Colorado. B. Amarillo, Texas. C. Qu'Appelle, Saskatchewan.

ing evaporation, so that twenty inches in North Dakota is equal to about thirty inches in Texas. Hence, western Texas is climatically drier than North Dakota.

The Great Plains rainfall regime has a distinct minimum for the six months making up the colder half of the year, October to March, and a maximum for the warmer half. (See Fig. 44.) Northwest Texas shows a tendency to late summer rains similar to the regime previously noted at El Paso; the maximum is in August, but the difference in the monthly amounts from May to September, inclusive, is less than one inch. On the eastern slope of the mountains, July is usually the wettest month; on the lower plains to the eastward, the maximum occurs in June. Throughout the region the six months, April to September, receive about 70%

of the annual total. The winters are dry; the four months, November to February, usually receive less than one inch of rainfall per month. In the southern half of the Plains much of the winter precipitation is rain, but occasional snows occur to the southern border of the region, where they average about one inch per year. In Oklahoma the average annual snowfall is about ten inches; in Kansas, about twenty inches; in the rest of the region, between twenty and forty inches.

In summer, low pressure develops over the interior of the continent, and the prevailing winds over the Great Plains are accordingly from the south and southeast. In winter the winds are prevailingly from north or northwest, out of the central high pressure area. This monsoonal change of direction results in an inflow of warm, moist, tropical maritime air from the region of the Gulf of Mexico, and some air also from the Pacific Ocean, during the summer months, and an outflow of cold, dry, continental air in winter. Hence, there is much more moisture in the air in summer than in winter. The summer heating of the surface air also contributes to establishing an unstable condition. In spring the rains are frequently purely cyclonic, slow, steady rain along the warm front of moving cyclones. In summer, thermal convection is more evident, and most of the rain occurs in the form of thundershowers. Hence, it is unevenly distributed in any one precipitation period—heavy in some localities, and light or absent in others. Those small destructive, whirling storms, named *tornadoes,* and originating in violent convective currents, are of frequent occurrence in the Great Plains, particularly in Texas, Oklahoma, Kansas, and Nebraska.

In the western portion of the Great Plains the conditions favoring rain are somewhat different from those just described. Low pressure in the Missouri Valley results in westerly winds and dry descending air on the eastern slope of the Rockies, and hence no rain. On the other hand, high pressure over the Missouri and upper Mississippi Valleys, and low pressure on the west of the Mountains, result in easterly winds moving up-slope across the mountains. This wind movement produces rain in the eastern portions of Colorado, Wyoming, and Montana, under conditions which are attended by dry weather in other parts of the Great Plains. Except for this orographic effect, the winter precipitation

of the Great Plains is cyclonic. It is often in the form of rain on the warm front, but changes to snow when the cold front arrives.

The occurrence of the greater part of the rain in the early part of the growing season is especially favorable for the production of grasses and small grains, and these are the principal crops of the Great Plains. The typical native vegetation is composed of short prairie grasses and bunch grasses, and the region is therefore a natural grazing country. Cattle raising is an important industry. On their western boundary the short grasses merge into mesquite in Texas and New Mexico and into sage brush in Colorado, Wyoming, and Montana; on their eastern side the transition is to the tall grasses of the prairie regions. From Kansas northward into Canada most of the native sod has been broken and the land given over to the growing of wheat—winter wheat in Kansas and southern Nebraska, spring wheat in northwest Nebraska, the Dakotas, Montana, Alberta, and Saskatchewan.

There is, however, great variability in the annual totals of rainfall from year to year, especially in the amounts during the growing season. Crop failures are therefore frequent. The percentage variation is greater here than in more humid regions, and the results of variations below the normal are more serious because the normal is barely sufficient to produce crops. Hence, the drought risks are great. Moreover, the actual amounts are more often below the normal than above, because the mean is largely affected by the occasional occurrence of an unusually wet year. The great variability results in the same station having a desert climate one year and a subhumid climate another year. The average rainfall is so light that the subsoil is permanently dry and there is little reserve for dry periods. There are periods of extension and of recession in the cultivated area, corresponding to the recurring series of wet and dry years.

The eastern boundary of the Great Plains is not marked by any abrupt change in conditions, topographically or climatically. There is merely a gradual merging into more humid conditions eastward, and since the rainfall is highly variable, the actual climatic boundary changes from year to year. (See Fig. 4.) In the north the isohyet of twenty inches shifts from year to year all the way from Montana to Wisconsin. The twenty-inch line, therefore, does not furnish a fixed line of demarcation. Other criteria

used are the boundary between the black soils of the more humid region to the east and the brown soils typical of the Plains, and the boundary between the native tall grasses and the short grasses. All these indicate an eastern boundary of the steppe climate between the 98th and 100th meridian, but in fact the boundary is a shifting one. There is a transition zone, as is the case with other climatic divisions, but it is somewhat more evident here than usual.

CHAPTER XII

Subtropical Climates of the United States

There are two types of climate to which the name *subtropical* is commonly and specifically applied. These are the humid subtropical (STH) and the dry subtropical or Mediterranean (STM) climates. The former occurs characteristically on the east coasts of continents, and occurs in the United States in the Gulf and south Atlantic coastal areas. The latter is a west coast climate and is represented in the United States by southern and central California. A limiting condition applied to both climatic types is that the mean temperature of the coldest month is less than 64°, but more than 43°.

The Humid Subtropical Climate of the Southeastern States (STH)

Beginning in central Texas at the 100th meridian and latitude 33° North, the January isotherm of 43° extends ENE. across extreme southern Arkansas and thence across the northern portions of Mississippi, Alabama, Georgia, and South Carolina, and across the southeastern portion of North Carolina. The area south of this line constitutes the humid subtropical region of the United States (except that extreme southern Florida is tropical). In this region there are nine to twelve months with average temperatures above 50°. The growing season is about 220 days in length along the northern border of the region, increasing southward and becoming continuous along a narrow coastal strip and in the Florida Peninsula. The humid subtropical province forms the southern half of the great Cotton Belt of the United States. The northern half extends northward into Oklahoma, Arkansas, Kentucky, and Virginia. This is the largest cotton producing area of the world. In its origin cotton is a tropical, perennial plant, but in the United States it is grown as an annual crop where the growing season is 200 days or longer. It cannot survive even the mild winter temperatures of these states.

Winds

Throughout the region the winds are predominantly from a southerly direction during the summer months, and they bring warm, moist, ocean air to the lands. In winter, the winds are variable, alternating between the warm, tropical marine air and cool northerly winds from the continental interior. Severe cold waves occur occasionally under the following meteorological conditions: an active and well-developed cyclonic area moves eastward across the southern states, closely followed by an area of high pressure and cold air that has moved southward from Canada. Under these conditions the air is drawn rapidly southward without time to be much warmed, and freezing temperatures extend to the coast line and into Florida. The frequency and severity of these cold waves decrease from north to south, and it is their frequency and severity, rather than the average temperatures of the winter months, that determine the length of the growing season and the distribution of subtropical vegetation.

On the Gulf coast the northern limit of the growth of evergreen subtropical plants coincides very nearly with the isotherm of 52° for the coldest month. On the south Atlantic coast the isotherm of 50° more nearly represents the inland boundary of such plants. The difference between the Gulf and Atlantic coasts in this respect lies in the fact that the cold air from the northern interior reaches the Gulf coast a day earlier than it does the Atlantic coast, and is therefore somewhat colder. At rare intervals even zero temperatures have occurred along both coasts, including northwestern Florida, but not in the rest of Florida. South of the isotherms of 50° and 52° there is normally some vegetation throughout the year, and the average length of the season between the last killing frost in spring and the first in autumn is 250 days or more.

Temperature

The summers are long and hot, but temperatures above 100° are rather rare. During June, July, and August, however, average maximum temperatures range from 85° to 95°, and average minimum temperatures are slightly above 70°. Mean daily temperatures are above 70° for five months in most places and for as many as seven months at some coastal stations and in Florida. Relative humidity during the summer months averages 70% to 75%. Since

these rather high temperatures and humidities continue for several months with little interruption, the summers are rather oppressive and enervating. The winters, on the other hand, are very pleasant except when the chilling northers blow. In the main this is a level coastal lowland, and there are few topographic features to produce temperature differences of much importance; such

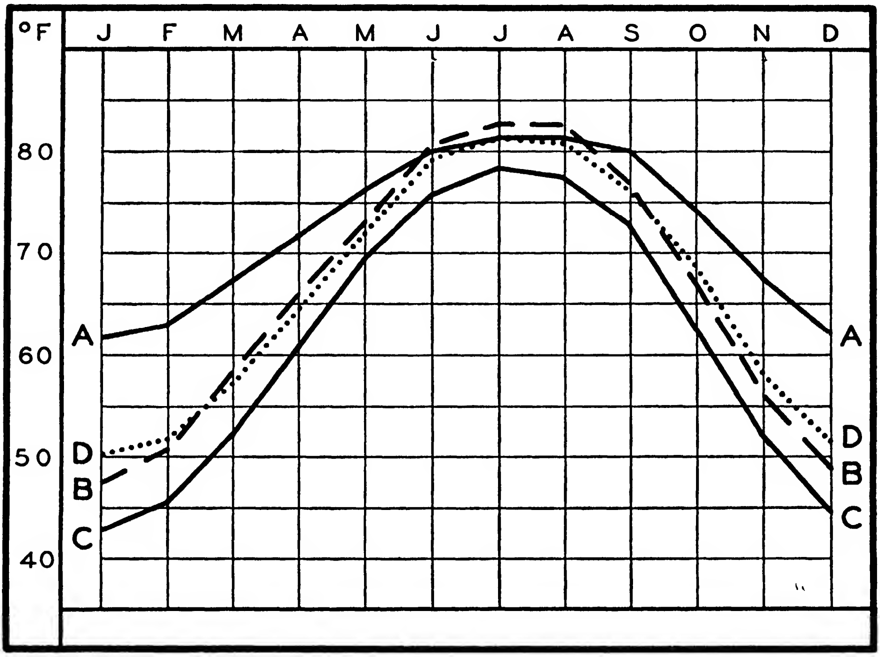

FIG. 45—Average Temperature. Humid subtropical climate of the United States.
A. Tampa, Florida. C. Atlanta, Georgia.
B. Shreveport, Louisiana. D. Charleston, South Carolina.

differences as exist are more closely related to distance from the coast. As will be noted in Fig. 45, temperatures along the coast are much the same from Texas to North Carolina, especially in summer. In the winter months the differences are greater; Tampa receives much less cold air than does Charleston. Farther inland, Shreveport is cooler in winter and slightly warmer in summer than are the coastal stations; Atlanta is cooler in all months. Additional data are given in the accompanying table.

Rainfall

The annual rainfall ranges from forty to sixty inches, except in Texas, where it decreases westward to about twenty-five inches

on the western border of the region. In general, the rainfall is moderate in all months, with a maximum in summer and a minimum in October and November; there are, however, some local differences to be noted later. The winter rainfall is mostly cyclonic in origin, but the summer rainfall is largely convective, and thunderstorms are more frequent in the east Gulf coastal region than in any other lowland area in the United States. From the mouth of the Mississippi River to western Florida the average number of thunderstorms is sixty to ninety per year. Heavy hail and tornadoes are rare, however. Hurricanes occasionally invade the region, but they are not of yearly occurrence. (Hurricanes are most frequent on the Atlantic coast of Florida.) Snowfall is of little importance in the region; the annual amount ranges from about three inches on the northern border to none in the extreme south. The number of rainy days ranges from about eighty-five to 125. Cloudiness is considerable at all seasons, and the average annual sunshine is 58% to 66% of the possible amount.

Texas

Along the Texas coast from Corpus Christi to the Louisiana boundary, a coastal plain less than 100 feet in elevation extends inland fifty to seventy-five miles. Northward and westward from this plain, the surface rises to a tableland of moderate elevation, reaching 1,500 feet in the northwest portion of the area under consideration. The northern boundary, somewhat north of Dallas, is marked by the January isotherm of 43°. In the coastal plain the mean temperature of the coldest month, January, is above 50°, but temperatures of 32° or lower, brought by the northers, occur on an average of five to ten days a year. Maximum temperatures above 110° and minima below zero have been recorded. The length of the growing season ranges from about 230 days in the north to more than 300 days in some coastal situations.

The Texas portion of the humid subtropical province is not only drier than those parts farther east, but has a different rainfall regime, approaching the distribution found in the steppe climate of the Rio Grande delta and the Great Plains. This applies particularly to the western transition zone, and is illustrated by the record for Corpus Christi (Fig. 46). Here the annual rainfall is about twenty-five inches, with a maximum in September and a secondary maximum in May and June, corresponding to the early

Humid Subtropical Climate (STH) of the United States	*Mean Temperature, °F.*				*Av. Precip. (Inches)*			*Snow-fall (Inches)*	*Rel. Hum. %*	*Sun-shine %*	*Number of Days*			
	Year	*Coolest Month*	*Warm-est Month*	*Range*	*Year*	*Wettest Month*	*Driest Month*				*.01 in. or more*	*90° or above*	*32° or below*	*Grow-ing Season*
Houston, Texas	69.1	Jan. 53 3	July 83.3	30.0	46.00	May 4 68	Feb. 2 97	0 2	72	62	99	81	9	294
New Orleans, La.	69.5	Jan. 54.7	July 82.5	27 8	59.59	July 6 63	Nov. 3.49	0 3	77	59	120	51	5	259
Vicksburg, Miss.	65.7	Jan. 48.4	July 81.3	32.9	51 54	March 5 50	Oct. 2 70	2	74	64	109	56	18	253
Montgomery, Ala.	65.6	Jan. 48.6	July 81.6	33.0	52.02	March 6 31	Oct. 2.36	1	72	62	113	66	20	250
Macon, Georgia	64.3	Jan. 47.3	July 81.0	33.7	45.75	March 5.04	Oct. 2 33	1	72	65	112	57	30	236
Jacksonville, Fla.	69.2	Jan. 55 6	July 81.8	26.2	50.54	Sept. 7 39	Nov. 2.05	T	80	62	123	49	5	294
Wilmington, N. C.	63 2	Jan. 47.2	July 79.5	32.3	48.04	July 6.94	Nov. 2.07	2	80	64	124	23	27	239

T = Trace.

summer maximum found in the Great Plains. July and August are dry, as are also the winter and early spring months, December to April. Native vegetation of the region comprises areas of cypress, southern pines, hickory (including pecan), and oak. Corn,

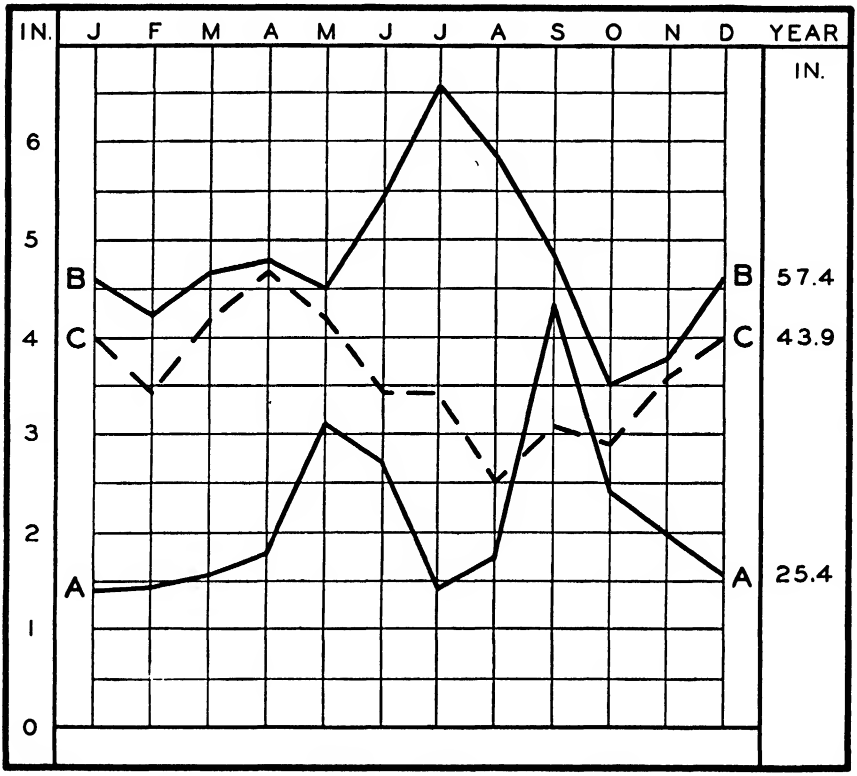

FIG. 46—Average Precipitation. Humid subtropical climate of Texas and Louisiana. A. Corpus Christi, Texas. B. New Orleans, Louisiana. C. Shreveport, Louisiana.

cotton, and winter-grown vegetables are important in the agriculture of the region.

Louisiana

The entire state of Louisiana is within the humid subtropical province. The average annual temperature of the state is 67°, and monthly mean temperatures vary from 52 in January and December to 82° in July and August. The length of the growing season is mostly between 220 and 250 days in the northern half of the state, and between 250 and 275 days in the southern half of

the state. A few places in the delta have a frost-free season of more than 300 days, and freezing temperatures extend southward to New Orleans an average of only five times a year. The lowest temperature at New Orleans in a record of fifty-seven years is 7°. At Shreveport in northern Louisiana the average number of days with minimum temperature of 32° or below is twenty-two, and the lowest temperature recorded is — 5°. On the immediate coast the daily range of temperature is 10° to 15°; inland it is 20° to 28°.

The annual rainfall of the state averages about fifty-five inches, with a minimum in autumn (see Fig. 46). In the southern half the maximum is in summer, with frequent heavy thunderstorm showers; in the northern half the winter and spring rains exceed those of summer. There is no dry season; the average amount of rainfall in September, October, and November is more than three inches per month, and in all other months between four and slightly more than six inches. Cane sugar is the principal product of the delta region, and is produced to some extent northward to the Red River; rice is grown in the prairies of southwestern Louisiana, and near the coast such subtropical fruits as oranges, olives, figs, and grapefruit are grown. Outside of these areas cotton is the principal crop.

East Gulf region

This region includes the southern two-thirds of Mississippi and Alabama and the western extension of Florida. This narrow coastal plain has a distinctly subtropical climate like that of the Louisiana delta. Temperatures average slightly lower, particularly in winter, because cold air masses moving down the Mississippi Valley drift eastward and reach the east Gulf coast somewhat more frequently than the western part of the coast. Zero temperatures have occurred at Mobile and Tallahassee, and freezing temperatures occur about ten times a year.

The rainfall in this coastal region is slightly greater than in any adjacent area, averaging a little more than sixty inches from extreme southeastern Louisiana to extreme western Florida. In addition the rainfall distribution has some characteristics peculiar to the region, having two distinct maxima and two minima (see Fig. 47). The July-August maximum is at the time of frequent

and heavy thunderstorms; the March maximum is at a time of spring cyclonic activity. In April and May cyclonic activity is much reduced and convectional instability not yet strongly established; hence there is a secondary minimum in these months. In

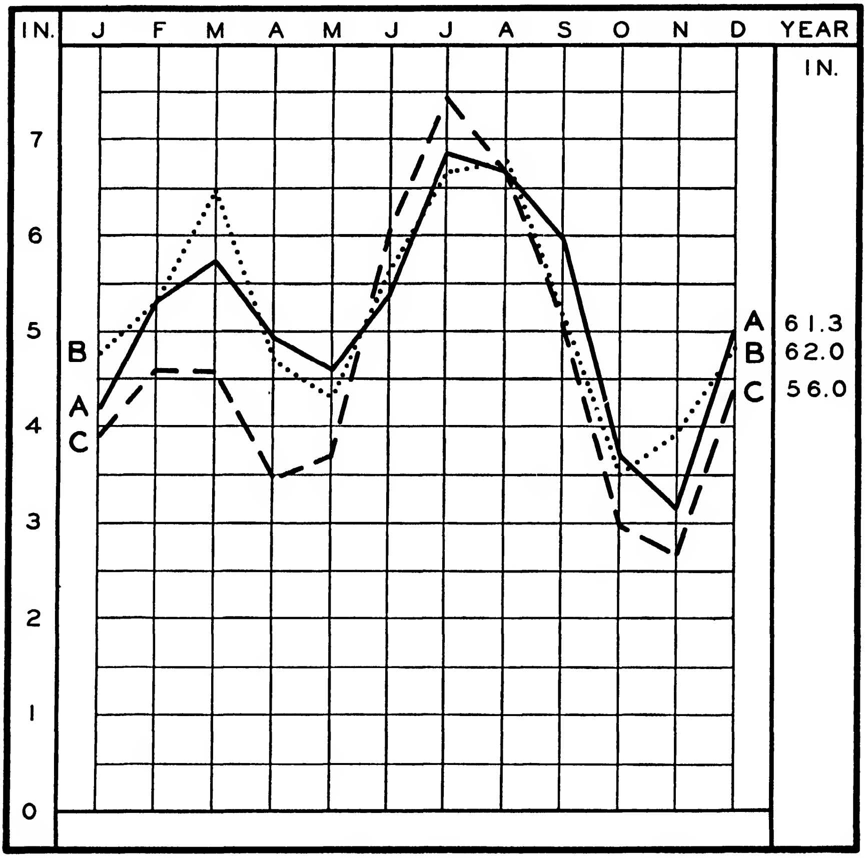

FIG. 47—Average Precipitation. Humid subtropical climate of the east Gulf Coast of the United States.
A. Biloxi, Mississippi. B. Mobile, Alabama. C. Tallahassee, Florida.

October and November dry, offshore, northeast winds representing the northern border of the trade winds prevail, and produce the primary minimum. In the northern portions of the area, the summer convectional rains are not as heavy, and the cyclonic rains of winter make the months of December to March the wettest of the year. Here the average rainfall is fifty to fifty-five inches a year. Pines and cypresses originally covered much of the sandy coastal

plains, and oaks predominated in the better, higher lands of the interior. Cotton is the outstanding crop of the region, but corn and truck crops are extensively grown.

The Florida peninsula

As previously noted, the southern end of Florida, from Lake Okeechobee southward, has a tropical rainy climate. The remainder of the Florida peninsula is humid subtropical, approaching truly tropical climatic conditions in the south. It is washed by the warm waters of the Gulf of Mexico and the Gulf stream; the greater part of the land is less than 100 feet above sea level, and no point is more than sixty miles distant from either the Gulf or the Atlantic Ocean. Hence the climate is distinctly marine and equable, subject only to occasional inflow of polar air, which, however, is much modified and moderated by the time it reaches the Florida peninsula. The leading industry is the production of citrus fruits and winter vegetables, a very direct response to climatic environment.

The mean annual temperature is about 68° in the north and 72° at the southern end of the subtropical province. January means range from 54° in the north to 64° in the south, and the July and August means are about 80°–82° throughout the region. The annual range decreases from 25° in the north to 15° in the south, and the daily ranges are approximately the same as the annual ranges. The lowest temperatures of record are 16° to 24°. Temperatures as low as 25°, and therefore injurious to subtropical plants and winter truck, occur about once in two years at Jacksonville, once in ten years at Tampa on the Gulf coast and at Titusville on the Atlantic coast, and once in forty years at Ft. Myers.

The annual rainfall of the subtropical peninsula averages forty-eight to fifty-four inches, generally adequate at all seasons but with a pronounced summer maximum. (See Tampa, Fig. 48.) Slightly more than half of the annual total falls in the four months of June to September—largely in afternoon thunderstorms of short duration. During these months rain falls on about half the days. Typically, the forenoon is clear; early in the afternoon cumulus clouds develop, and by late afternoon there is a shower, often heavy, but lasting only an hour or two; in the evening the skies clear. About 75% of the rainfall of these months occurs during the daylight hours. Rainfall averages five

to nine inches per month during this rainy season. From November to April the monthly average is from two to three and one-half

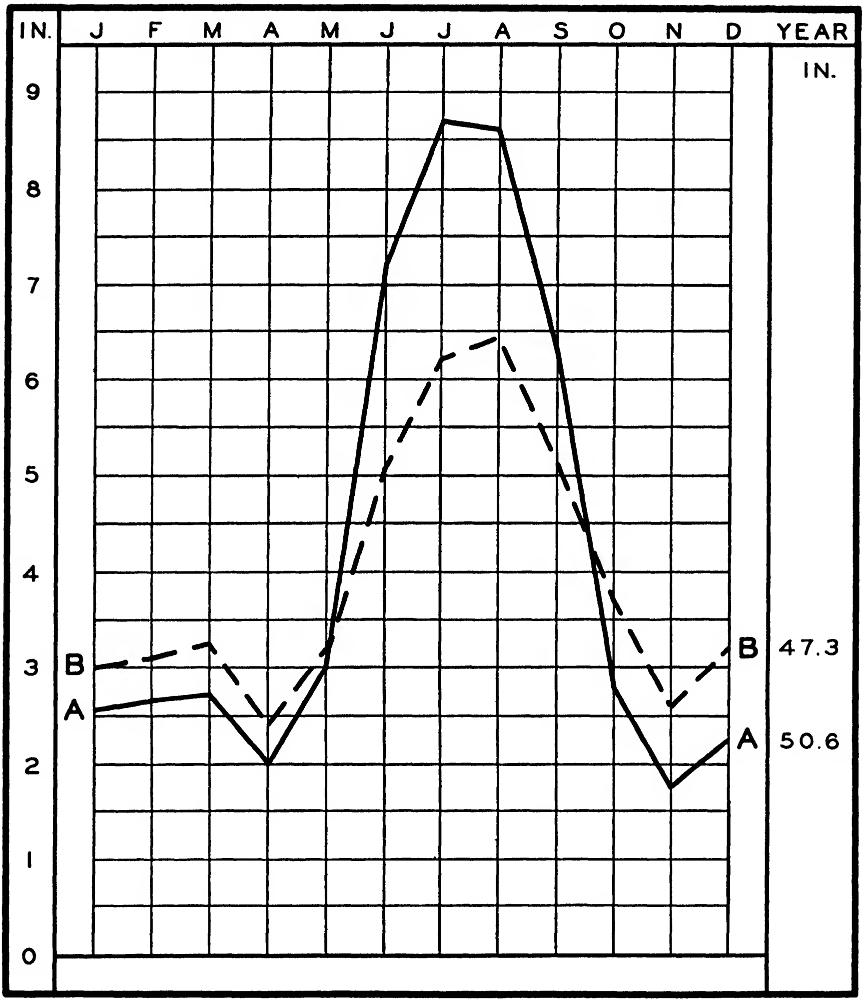

FIG. 48—Average Precipitation. Humid subtropical climate of Florida and South Carolina.

A. Tampa, Florida. B. Charleston, South Carolina.

inches, mostly cyclonic in origin. November and April are generally the driest months.

South Atlantic region

A large part of Georgia and South Carolina and the coastal plain of North Carolina form the eastern portion of the humid

subtropical province of the United States. Temperature conditions in this area are similar to those of the east Gulf Region. Annual temperatures average 60° to 67°; summer temperatures, 77° to 80°; winter temperatures, 45° to 53°. Freezing temperatures occur about ten times a year on the coast, and twenty-five to thirty-five times in the interior. The frost-free period ranges from 220 to more than 250 days in length. The rainfall regime is very similar to that of the Florida peninsula, but the amount is somewhat less, averaging forty-five to fifty inches. See Charlestown, Fig. 48, and data for Atlanta and Wilmington. The difference is largely in the somewhat less-pronounced summer maximum, thunderstorms being less frequent and less intense. The average number is fifty to sixty per year. Native plants include palmettos, magnolias, and live oaks, and cultivated crops include sugar cane, rice, and cotton.

The Mediterranean Climate of California (STM)

A large portion of California has a distinct type of climate quite different from that in any other part of North America, but similar to the climates of a few other rather small areas in other parts of the world. The type is called *Mediterranean climate* because it is most extensive on the shores of the Mediterranean Sea, and has been known there for 2,000 years. In the Northern Hemisphere the type occurs only in the Mediterranean Region and in California. In the Southern Hemisphere there are small areas in Chile, South Africa, and southern Australia.

The climate is characterized by warm to hot summers frequently tempered by sea breezes, by mild winters with temperatures seldom falling much below freezing, by an almost complete absence of rain for a period of two to six months during the summer, and by light to moderate rainfall during the winter months; during the winter the rainfall comes in periods of a few days' duration, separated by many days of brilliant sunshine. Distinctive characteristics are the mild winters and the summer droughts. The mean temperature of the coldest month is above 43°; there are occasional frosts, but in general growth is continuous. The percentage of sunshine is high. The lands with a Mediterranean climate are famous for their bright sunny days, blue skies, and abundance of fruits and flowers. In the United States the type

includes the coastal plains and valleys of California northward to San Francisco, numerous small valleys farther inland but west of the main ridge of the Coast Range, the large interior valleys of the Sacramento and San Joaquin Rivers lying between the Coast Range and the Sierra Nevada, and a small area in northwestern Baja California. Much of this region has an annual rainfall of less than twenty inches, and on the basis of rainfall might logically be classed with the steppe climates.

Climatic controls

The factors influencing the climate of California are: (a) its latitudinal position with reference to the general circulation, (b) its position on the eastern shore of an ocean, (c) the abnormally cool water of the Pacific off the coast, and (d) the presence of mountain ranges paralleling the coast. In summer the region is within the subtropical high pressure belt, which is an area of clear, dry, slowly descending air. With clear skies and a high sun, the land warms rapidly by day, but the ocean water, moving from the north, remains cool for its latitude. Sea breezes result along the coast, and extend into the interior valleys where there are openings in the Coast Range. The air thus brought inland and warmed as it moves over the land decreases in relative humidity and produces no cloudiness. By night the land cools rapidly by radiation through the clear air. The summers are warm and pleasant along the immediate coast; the temperatures are not often over 90°. Farther inland summers are hot, but they are dry and are not oppressive.

In the winter, as the pressure belts shift southward, the area comes under the influence of the prevailing westerlies. These bring moderately cool maritime air. Occasionally the cyclonic storms of the westerlies invade the region, attended by southerly winds and short rainy periods. The precipitation is in the form of rain in the lowlands, but much snow falls in the mountains. The lowest temperatures in the valleys occur on clear calm nights in winter when there is a gentle movement of continental air from the north. Under these conditions radiation cooling of the soil results in reducing the temperature of the air near the ground sufficiently to cause frosts. Occasionally these frosts are severe enough to injure the orange trees and other subtropical vegetation. Since

ordinarily the air is quiet and only a thin layer cools to injurious temperatures, it is possible to protect orchards from injury by the use of many small fires distributed between the rows of trees. Small oil-burning heaters are used to radiate heat directly to the trees and to the air; smoke is avoided as much as practicable. The method is less effective when there is considerable wind. It is extensively and successfully used in California to protect both citrus crops and trees.

Northerly winds of quite a different character occasionally occur in the valleys of California, especially in spring and in autumn. Air out of centers of high pressure over eastern Oregon, Washington, and British Columbia moves over the mountains, losing some of its moisture on the northerly slopes, and descends into the California valleys at velocities of fifteen to twenty-five miles per hour as a dessicating, irritating wind of true foehn character. The relative humidity is frequently less than 20%. Occasionally the turbulent lower layer of this moving air mass picks up much dust, and the *norther* becomes a *sandstorm.* Although of different origin, these northers are similar in their effect on vegetation to the southerly *hot winds* of the Great Plains. They are quite different from the cold northers of the southern Great Plains.

Along the immediate coast from the Santa Barbara Channel northward, fogs are frequent and dense, forming at night in the marine air brought in by the afternoon sea breezes. They supply and conserve much moisture and permit the growing of many crops without irrigation, although the rainfall is light. Closely related to these fogs are the so-called *high fogs,* which are really stratus clouds (locally called *velo clouds*). High fogs are a feature of the coastal climate from San Diego to San Francisco, and are especially frequent in summer. They form mostly at night at heights of 1,000 to 4,000 feet, and they generally dissolve during the forenoon under the warming influence of the sun. They develop near the top of a surface layer of cool, moist air from the ocean which is overlain by a layer of warm, dry air from the interior. The principal cause is convective turbulence in the unstable moist air, aided by radiational cooling of its upper surface. At the coast these *high fogs* cause a large number of partly cloudy days, and they reduce the sunshine to 60% or 65% during the almost rainless summer months. Only a short distance inland the sun-

Mediterranean Climate (STM) of California	Mean Temperature, °F.				Av. Precip. (Inches)			Snowfall, (Inches)	Rel. Hum. %	Sunshine %	Number of Days			
	Year	Coolest Month	Warmest Month	Range	Year	Wettest Month	Driest Month				.01 in. or more	90° or above	32° or below	Growing Season
Southern California														
San Diego	61.1	Jan. 54.7	Aug. 68.8	14.1	9.67	Feb. 1.90	July 0.05	0	76	69	44	1–	1–	365
Riverside	62.8	Jan. 51 9	July 75.8	23.9	10.89	Jan. 2.16	July 0.02	0		.	39	. . .	. . .	270
Los Angeles	62.7	Jan. 55.1	Aug. 71.2	16.1	14.95	Jan. 3 06	July 0.01	0	69	72	37	13	1–	359
Azusa	62.5	Jan. 52.1	Aug. 74.4	22.3	19.23	Jan. 4.55	July T	0	. .	. .	38	. . .	. . .	282
Central California														
Tulare	62 8	Dec. 46.9	July 80.7	33 8	8.21	Jan. 1.69	Aug. T	.	. .	.	38	. . .	. .	249
Monterey	56.7	Jan. 50.3	Aug. 62.1	11.8	16.71	Jan. 3.47	Aug. 0 02	. .		. .	44	. . .	. .	305
San Francisco	56.2	Jan. 49 9	Sept. 61.3	11.4	22.01	Jan. 4.70	July 0 01	T	78	65	66	1	1–	350
Stockton	59.8	Jan. 45.7	July 73 5	27.8	14.10	Jan. 2.92	July T	.	.		44	. .	. .	291
Red Bluff	62.3	Jan. 45.2	July 81.5	36.3	24.31	Jan. 4.64	July 0.03	3	56	72	70	84	13	272

T = Trace.

shine is 70% to 75%, and farther inland the interior valleys have almost uninterrupted clear weather.

Southern California

That portion of California south of the Tehachapi Mountains and west of the southeastern extension of the coastal ranges is the typically subtropical portion of the state. Differences in elevation, exposure, slope, and distance from the ocean give a great variety of local climates, but rainfall is light everywhere except in

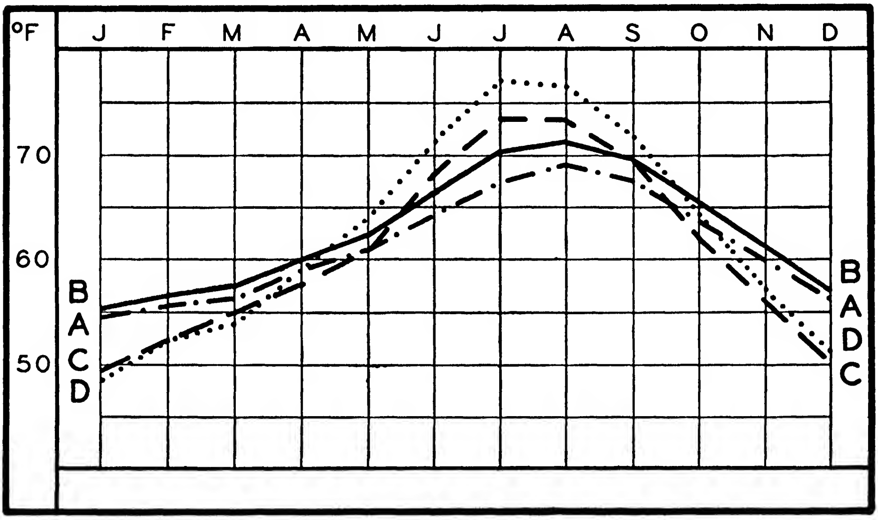

FIG. 49—Average Temperature. Mediterranean climate of southern California.
A. San Diego. C. Pomona.
B. Los Angeles. D. San Jacinto.

the high mountains, and more than 75% of it falls in the wet season, November to March, inclusive. In the lowland the amount ranges for the most part from ten to twenty inches, but some favorably situated stations at moderate elevations receive twenty-five to thirty inches. The highest peaks are covered by deep snow in winter, but no peak remains covered all year. The rainfall is cyclonic, and thunderstorms are rare except in the mountains.

Summer maximum temperatures increase rapidly from the coast inland, and winter minima decrease. The interior valleys, some of which have elevations of 1,000 to 2,000 feet, have hot summers and cool winters. Summer temperatures often exceed 100°, and winter temperatures fall below freezing. Citrus fruits

are not grown commercially under these conditions, although the average temperature of the coldest month is above 48°. The immediate coastal region, especially from Los Angeles to San Diego, has a very equable climate. The summers are rainless and moderately warm, maxima seldom exceeding 90°. The warmest month is August. The winters are so mild that frosts are rare and snow never falls; January mean temperatures are above 50°. There are occasional rainstorms in winter, but there is also much sunshine.

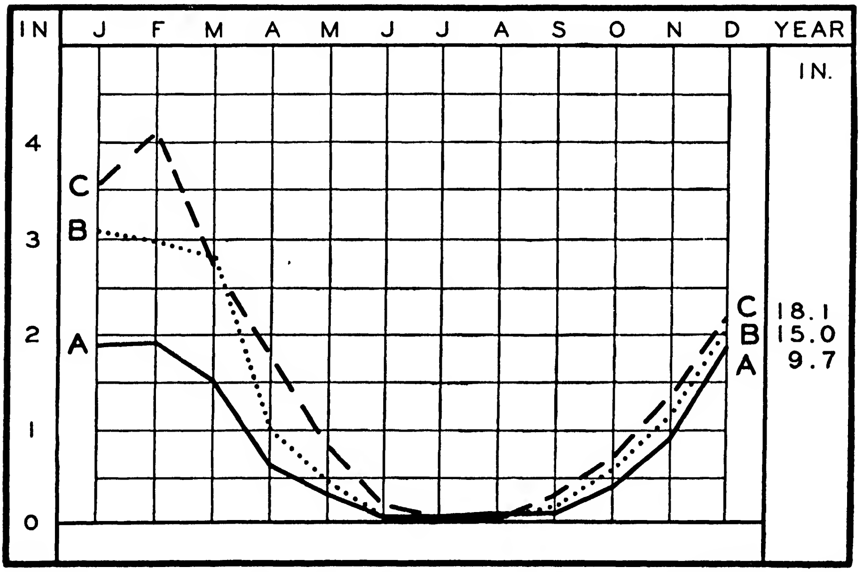

FIG. 50—Average Precipitation. Mediterranean climate of southern California. A. San Diego. B. Los Angeles. C. Pomona.

San Diego has an average annual rainfall of 9.67 inches, with forty-four rainy days, the highest average number per month being seven in February and in March. The average sunshine is 69%, with a minimum of 59% in May (because of the frequent high fogs at this time of year) and a maximum of 77% in November. Los Angeles, a short distance inland and at an elevation of 338 feet, has 14.95 inches of rain per year, occurring on thirty-seven rainy days. The number of rainy days averages six a month from December to March, inclusive. Here the sunshine averages 72% of the possible amount, increasing from a minimum of 63% in May to a maximum of 79% in August. The winter average is 70%. Climate is the primary reason why much of this coastal

region is densely populated. Its climate makes the region well adapted to the intensive cultivation of valuable crops and also makes it attractive at all seasons of the year as a pleasure and health resort. In addition to citrus fruits, English walnuts, deciduous fruits, and truck crops are extensively grown.

Differences in the subtropical climates of Florida and California are indicated in the following table:

	Temperature							*Average No. of Days*	
	Annual mean	*Summer mean*	*Winter mean*	*August mean*		*Absolute*		*32° or less*	*90° or over*
				Max.	*Min.*	*High*	*Low*		
Tampa	72	81	62	90	74	98	19	1	56
Jacksonville	69	81	57	89	74	104	10	5	49
San Diego	61	67	55	74	64	110	25	*	*
Los Angeles	63	69	56	82	60	109	28	*	13

* Less than one day.

Both by day and by night, the Florida coast is decidedly warmer in summer than is the California coast, although the California stations have recorded higher absolute maxima. Florida averages moderately warmer in winter, but has occasional temperatures considerably lower than those recorded at San Diego and Los Angeles. A short distance inland temperature conditions change much more in southern California than in Florida; the summer maxima become higher than in Florida, and the mean winter minima are decidedly lower. These figures reflect the difference in the temperature of the adjacent water surfaces on eastern and western shores of the oceans, the differences in continental influence, and the difference of 4° to 5° in latitude.

The Central Valley

The great Central Valley of California, comprising the valleys of the Sacramento and San Joaquin Rivers, presents a somewhat less tropical appearance than does southern California, but produces citrus fruits and other subtropical crops in favored regions in the foothills where air drainage is good. Mean July temperatures are mostly above 75° and mean January temperatures above 45°.

Monthly isotherms run north and south in these valleys, but summer daytime temperatures are somewhat higher in the southern part of the San Joaquin Valley and in the northern part of the Sacramento Valley than in the lower portions of these valleys. This is because the sea breeze enters through the gap by which the rivers flow to the bay, and its cooling influence decreases as it moves up the valleys. Compare the curves for Fresno, Red Bluff, and Sacramento in Fig. 51. Along the valley sides the isotherms

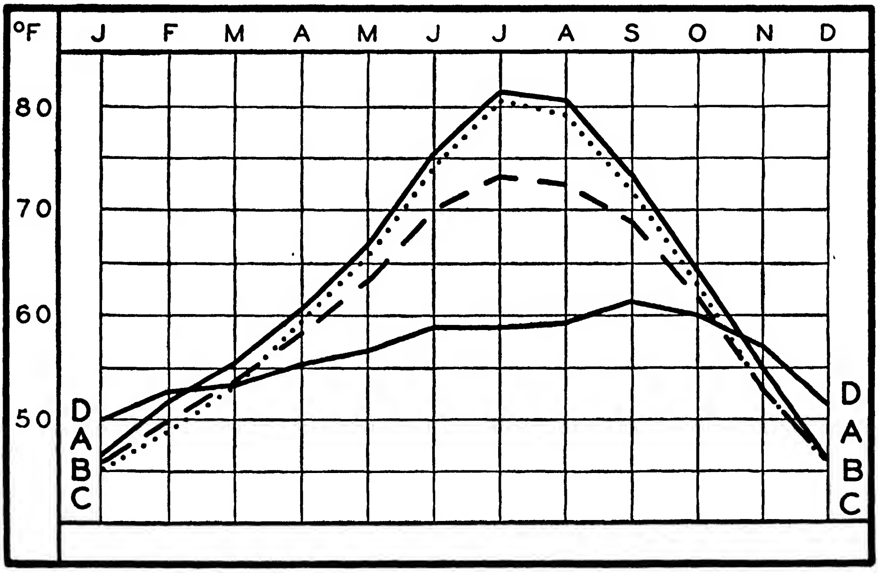

FIG. 51—Average Temperature. Mediterranean climate of central California.
A. Fresno. C. Red Bluff.
B. Sacramento. D. San Francisco.

largely conform to contours; that is, the thermal conditions depend upon elevation and upon the sheltering influences of adjacent mountains and foothills. The climate is often subdivided for agricultural purposes into *valley, foothill,* and *mountain climates.* Large acreages of the extensive, level, valley lands are devoted to intensive agriculture under irrigation, producing great quantities of grapes, apricots, peaches, pears, and plums.

In most of the San Joaquin Valley the rainfall is less than fifteen inches, decreasing from north to south. May to September, inclusive, are practically rainless. (See Fresno, Fig. 52.) Maximum temperatures of summer exceed 110°, but radiation cooling

is rapid in the very dry air of summer, and the daily range is 40° or more. Summer nights are thus usually comfortably cool. Frosts occur during the winter from about the beginning of December to the end of March. In winter, radiation fogs are of frequent occurrence and sometimes attain considerable depth. Winds are light and prevailingly from the northwest, moving up the valley. The dry air and unbroken sunshine of summer and early autumn are features of the climate especially adapted to the pro-

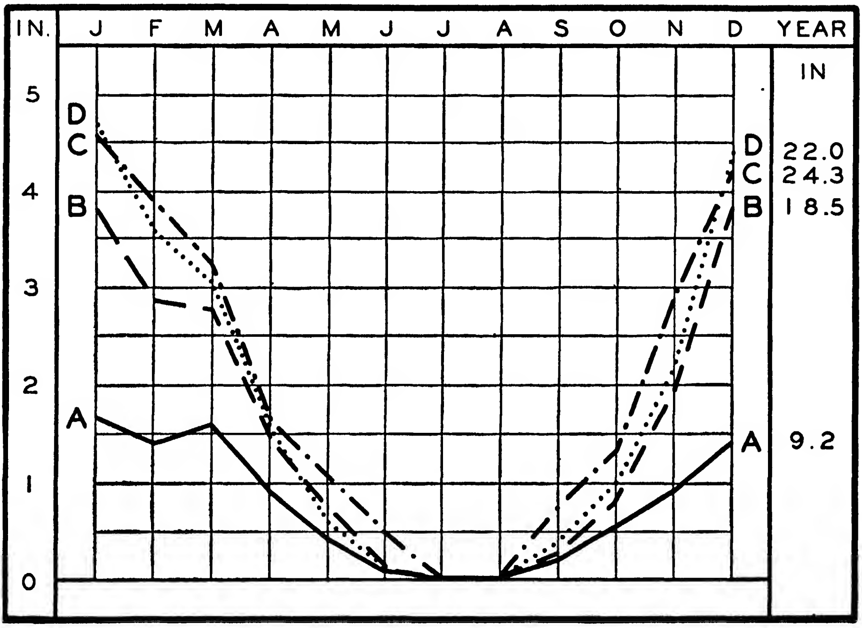

FIG. 52—Average Precipitation. Mediterranean climate of central California.
A. Fresno. C. Red Bluff.
B. Sacramento. D. San Francisco.

duction of raisins, and Fresno is the center of the raisin industry of the United States. At Fresno the annual rainfall averages only 9.19 inches, and the number of rainy days in a year is only forty-three. Sunshine averages 78%, with a minimum of 44% in January and a maximum of 96% in July and August.

The Sacramento Valley has similar temperature conditions, but has a somewhat greater rainfall—eighteen to thirty-five inches—and a shorter summer drought. There are spring and autumn, as well as winter, rains, but July and August are without appreciable rain. (See Sacramento and Red Bluff, Fig. 52.) Movement

of air is from the south; the westerly winds that enter from the Bay region are deflected up the Valley.

The San Francisco Bay region

This region is marked by notably cool and late summers and by relatively warm winters. September is the warmest month and January the coolest. There are fresh sea breezes in the afternoon and frequent fogs at night. At San Francisco the average temperature in September is 61°, the average maximum being 68° and minimum 55°. Thus, even in midsummer, warm clothing and some heating of homes are required. October is warmer than June, July, or August (see Fig. 51). In winter the average daily maximum is 56°, and the average daily minimum is 46°. The annual range of temperature is about 11° as compared with 28° at Sacramento and 36° at Fresno and Red Bluff. At San Francisco there is an average of only one day a year with a temperature as high as 90° and less than one day a year with a minimum as low as 32°. The climate is quite definitely marine.

Mountain regions

Rainfall is heavy on the western slopes of the Sierra Nevada Mountains, in many places amounting to fifty to seventy-five inches per year. The maximum rainfall occurs between 3,500 and 6,500 feet elevation. Snowfall is very heavy in the high Sierra during the winter; several records show average amounts for the season from 200 inches to as high as 450 inches. The gradual disappearance of this snow during the summer is of great economic value as a constant source of water for irrigation of the valley lands. These mountains do not remain covered all year; during the late summer and early fall months snow is to be found only on the shaded portions of the highest peaks and in deep canyons on the northern slopes of the higher mountains. The Sierra Nevada of California are heavily forested with sequoias, pines, spruces, and firs. The trees, which are of great size and beauty and of many species, constitute what is probably the finest coniferous forest of the world. On the eastern slopes of the Coast Range precipitation is moderate—twenty to forty inches a year.

CHAPTER XIII

Humid Intermediate Climates of North America

The two subtropical climatic provinces discussed in the previous chapter merge on their northern sides into cooler regions where at least one month has a mean temperature below 43°. These regions have a distinct winter season, during which plant life is dormant. The climates cease to be subtropical and are called *intermediate,* or *middle latitude, climates.* On the Pacific coast the transition is from the Mediterranean type (STM) to a cool humid marine type (IM) characteristic of west coasts in middle latitudes. It is found in similar latitudes on the west coasts of Europe and South America. The humid subtropical type (STH) of the southeastern states merges into an intermediate humid continental type (IC) which is divided into three subtypes.

The Cool, Humid, Marine Climate of the Pacific Coast (IM)

Along the Pacific coast of North America from northern California to the southern coastal region of Alaska (from latitude 38° N. to 60° N.) a mild, wet, marine climate prevails. The distinctive features of this climate are the mild winters and cool summers, the high average relative humidity, the large number of rainy days, and the moderate to heavy rainfall with winter maximum. The presence of mountain ranges paralleling the coast limits this climatic type to a narrow belt, mostly forty to 100 miles wide. In California it is confined to the coastal valleys west of the Coast Range and north of San Francisco. In Oregon and Washington the type crosses the lower coastal mountains and prevails in a modified form until the western slope of the Cascades is reached. In British Columbia and Alaska the Coastal Ranges form the eastern boundary. These mountain ranges from California to Alaska not only limit the eastward extension of marine influences, but also serve as a barrier to the westward extension of continental influences, thereby making this narrow strip one of the most characteristically marine coasts of the world.

Pressure and winds

The North Pacific Anticyclone, the Aleutian Low, and the California ocean current are the dominant factors in the weather of this coast. In winter the Aleutian Low is strongly developed in the Gulf of Alaska, and winds blow into this depression from the northern side of the high pressure area off the coast of California, giving prevailingly southwest winds from northern California to southern Alaska. In summer the Pacific High moves northward, and a ridge reaches into the Alaskan Gulf. Meanwhile, low pressure develops over the arid southwest and forms a center in Arizona. Thus summer winds in the coastal region are from the northwest.

Throughout the year this coast is bathed in air moving directly from a cool water surface. The winters are chilly and damp, but the southwest wind from the ocean brings no cold waves. The summers are remarkably cool, especially in the southern portions of the belt (considering its latitude), for the wind is from the north, and the water over which it passes is relatively cooler than in winter. These are the usual conditions, but occasionally easterly winds from an interior anticyclone bring continental influences to the coast. Such winds are dry and hot in summer and cold in winter. Cyclonic areas from the North Pacific region of low pressure, attended by rain, move inland frequently during the winter months, but in summer the ridge of high pressure off the coast prevents the development of such disturbances. There is a rather large total wind movement along this entire coast, and gales are moderately frequent during both summer and winter.

Temperature

In the accompanying table note that January mean temperatures range from 47° at Eureka, California, to 27° at Juneau, Alaska. These temperatures are approximately the same as the January temperatures at Shreveport, Louisiana, and at St. Joseph, Missouri, respectively, although Eureka is 9° of latitude north of Shreveport and Juneau is 18° north of St. Joseph. July or August temperatures range from 67° at Roseburg and Portland, which are not on the immediate coast, to 56° at Eureka. Note that this most southerly station of the group is also the coolest in summer. Indeed, the northern California coast has the lowest mid-summer

temperatures of any part of the United States. The reasons for this are: (a) the cold ocean current comes nearest to the shore in this region; (b) the coast line faces somewhat north of west; (c) there are fresh onshore, northwest winds; and (d) clouds and fog reduce the average sunshine to less than 50%. Because of the warm winters and the abnormally cool summers, the mean annual range of temperature at Eureka is only 9°; this is a remarkably uniform temperature condition for any place outside of the Tropics. The highest temperature ever recorded at Eureka is 85° and the lowest 20°; this is an absolute annual range of only 65°, the smallest of any station in continental United States. Daily ranges of temperature are about 20° or less during the summer, and 10° or less during the winter.

From Eureka to Juneau, a distance of about 18°, the stations in the table are arranged in order of latitude, but temperatures show no close relation to latitude, being more influenced by local exposure and distance from the ocean. The isotherms run almost north and south, and are closely crowded in an east-west direction —that is, with distance from the coast, temperatures become rapidly higher in summer and lower in winter. The interior valleys have greater amplitude of temperature ranges, lower average humidity, less cloudiness and fogginess, and lighter winds. Portland has had a maximum of 105° and a minimum of —2°, but neither Seattle nor Vancouver has recorded temperatures as high as 100° or as low as zero. Victoria's absolute maximum is 95°, and its absolute minimum is —2°. The extremes both in winter and in summer are due to the invasion of continental air.

Growing season

The number of months with mean temperature above 50°, and hence favorable for plant growth, is seven on the California coast, six or seven on the coast of Oregon and Washington, five or six on the southern coast of British Columbia, and four in northern British Columbia and southern Alaska. Owing to the small daily range of temperature and the infrequency of sharp falls in temperature, the season between killing frosts, or the season of growth of hardy vegetation, is longer than is indicated by the number of months averaging above 50°. In some favored coastal positions from California to Tatoosh Island at the entrance to the Strait of

West Coast Marine Climate (IM) of North America	Mean Temperature, °F.				Av. Precip. (Inches)			Snow-fall (Inches)	Rel. Hum. %	Sun-shine %	Number of days			
	Year	Coolest Month	Warm-est Month	Range	Year	Wettest Month	Driest Month				.01 in. or more	90° or above	32° or below	Grow-ing Sea-son
Eureka, California	51.6	Jan. 47.0	Aug. 56 3	9.3	39.04	Jan. 6.98	July 0.11	0.4	85	46	120	0	4	277
Roseburg, Ore.	53.3	Jan. 41.0	July 67.4	26.4	32.41	Dec. 5.31	July 0.32	7	74	..	133	14	35	217
Portland, Ore.	53.1	Jan. 39.1	July 67.2	28 1	42.25	Dec. 6.74	July 0.57	14	74	45	154	6	28	251
North Head, Washington	50.1	Jan. 41.6	Aug. 58.1	16.5	48.84	Dec. 7.90	July 0.62	5	87	43	192	1 –	1	294
Seattle, Washington	51.4	Jan. 39.8	July 63.8	24.0	30.87	Jan. 4.95	July 0.59	14	77	43	151	1 –	22	251
Victoria, B. C.	49.4	Jan. 38.6	July 59.9	21 3	29.70	Dec. 5.58	July 0.39	15	80	..	148	....	...	...
Vancouver, B. C.	49.1	Jan. 35.6	July 63.3	27.7	58.65	Nov. 9.52	July 1.23	30	81	38	163	....	...	...
Prince Rupert, B. C.	45	Jan. 33	Aug. 57	24	100.93	Oct. 12.97	June 4.14	.....	79	..	...	....	...	...
Juneau, Alaska	42.0	Jan. 26.7	July 57.4	30.7	80.57	Sept. 10.68	June 3.73	114	..	32	206	0	108	164

Juan de Fuca, the growing season is as much as 300 days in length. It is more than 200 days in the coastal valleys of Oregon and Washington and in the Willamette Valley, but decreases to about 150 days in some of the valleys on the western slope of the Cascades in Oregon. It is mostly between 140 and 160 days at coastal stations in British Columbia and southeastern Alaska.

Precipitation

The rainfall ranges from moderate to very heavy, with a distinct winter or autumn maximum and summer minimum throughout the region (see Fig. 53). The amount is about sixty inches over much of the region, but it decreases to about forty inches in places; in a small area at the southern end of Vancouver Island, on the windward side, it increases to 200 inches, but Victoria, a few miles to the east, has only thirty inches. The rainfall is cyclonic and also orographic, as evidenced by the wide local variations. The cyclones move inland from the Aleutian Low and progressively farther southward as the season changes from summer to winter. In summer the Pacific Anticyclone dominates the weather of the southern half of the region, and the rainfall is light —less than an inch a month in July and August at Seattle and Portland, and a total of an inch in three months (June, July, and August) at Eureka. As winter approaches, the pressure belts and cyclonic paths move progressively farther south, the rainfall increases, and the month of maximum rainfall becomes progressively later. September is the wettest month at Juneau, with October nearly the same; November is wettest at Vancouver, December at Seattle and Portland, and January at Eureka.

Most of the precipitation occurs as rain, but there are occasional heavy snowstorms from the Columbia River northward. The annual total ranges from ten inches at places in the south to eighty inches in the Alaskan portion of the region. Snowfall is very heavy in the mountains that bound this coastal belt on the east. On the west slopes of the Cascades there are 300 to 400 inches of snow a year. There are also occasional severe "ice-storms" (ice layer—called *glaze* by the Weather Bureau—formed by rain freezing as it strikes cold surfaces). There are very few thunderstorms, approximately one to five a year. Most of the rain falls slowly and steadily; there is much cloudiness, a large num-

ber of rainy days, and a small percentage of sunshine. Periods of dark, dripping weather sometimes last for days or even weeks. Frequent dense fogs also reduce the number of hours of sunshine. Fogs form over the cold ocean water and drift inland at night or in

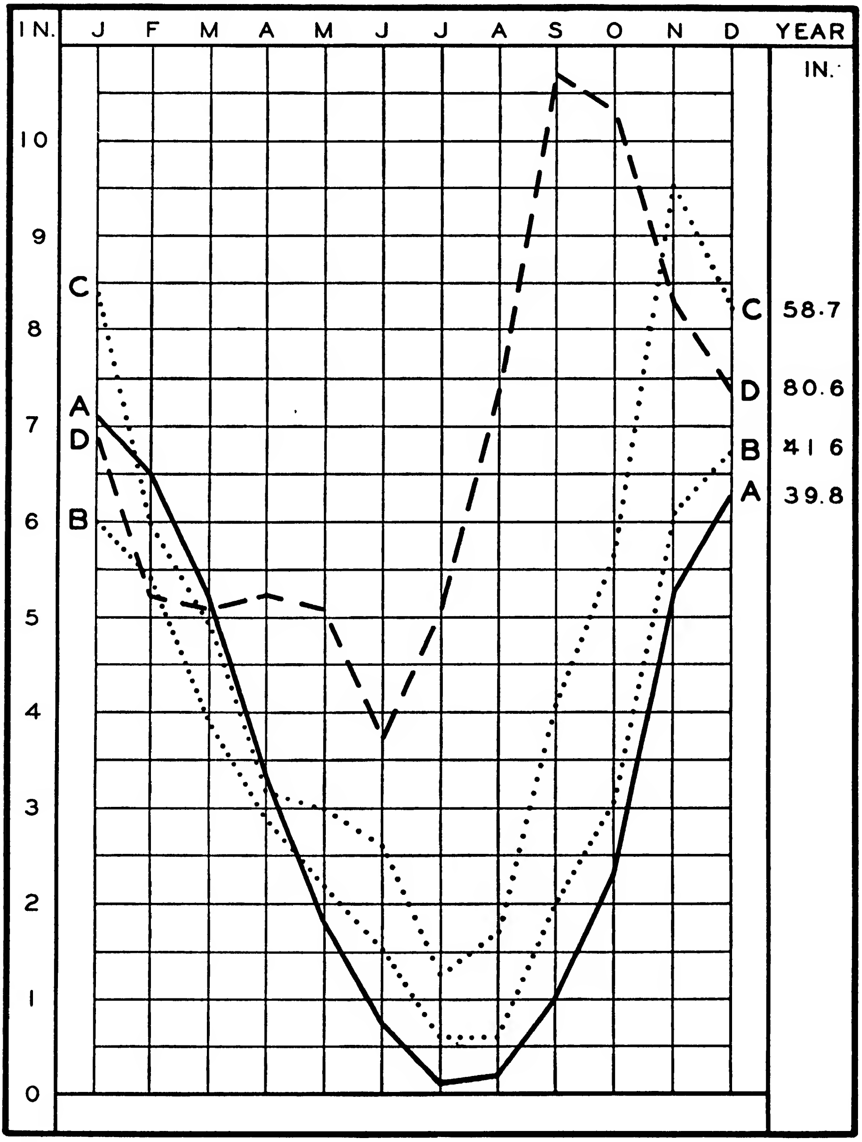

FIG. 53—Average Precipitation. Intermediate marine climate of North America.
A. Eureka, California. C. Vancouver, B. C.
B. Portland, Oregon. D. Juneau, Alaska.

the early morning. The number of rainy days ranges from 120 to more than 190. Sunshine is less than 50% in general and less than 40% in a portion of the California coast where fogs and "high fogs" (stratus clouds) are frequent in summer during otherwise clear weather. The air is always damp; along the immediate coast the relative humidity ranges from 80% to 90%; at Seattle it is 74%, and at Portland 70%.

Vegetation and man

Agriculturally this cool, humid, marine area is known as a hay, pasture, and forest region. Lumbering, grazing, dairying, and fruit growing are the principal occupations. The foggy coastal valleys and hills of northern California, with their slight ranges of temperature (always cool but never cold) constitute the native home of the great redwood forests. This species of redwood is found nowhere else in commercial quantity. The coastal valleys of California, Oregon, and Washington are especially suited to dairying because the grass remains green and growing all year. In the valleys a little farther inland, somewhat protected from the ocean, deciduous fruits, grapes, berries, vegetables, hops, hay, and grains are grown. In the marine valleys of British Columbia, hay, stock, and fruits are important products. The Alaskan coast has superb coniferous forests, and much of the mountain area throughout the region is still heavily forested.

The climate is stimulating, healthful, and conducive to human efficiency, although it is too cool for the best growth of many cereal crops. It is not severe, but it is often moist and chilly. Its disadvantages are the high relative humidity and the small amount of sunshine. The interior valleys are better in these respects. There is an extensive similar climatic type in northwest Europe and in New Zealand, and there are small areas in South America and Australia in similar latitudes.

General Features of the Humid Continental Province

The humid continental type includes all of the United States north of the humid subtropical province and east of the Great Plains, and includes also a strip of southern Canada. This province is rich agriculturally, and it contains a large part of the most

densely populated portions of the United States and Canada. Although the area included is large and has a wide divergence of temperature and rainfall conditions, classification into a single major type with three subdivisions is sufficient to bring out the salient features of the climate and to indicate the main vegetative regions. This is because the region is chiefly a wide plain in which climatic similarities persist over large areas, and transitions are gradual.

In these climatic regions the winters are cold and the summers are hot. Because of the great difference in the amounts of summer and winter insolation, this large difference between winter and summer temperatures is to be expected in continental climates in middle and high latitudes. Another characteristic of the continental climates of middle and high latitudes is that the latitudinal temperature gradients are much less in summer than in winter. For example, the mean temperature in July is 81° at Oklahoma City and 67° at Winnipeg; in January it is 37° at Oklahoma City and —3° at Winnipeg. There is a difference of 14° in summer and of 40° in winter. The annual distribution of insolation in the different latitudes is the primary cause of this difference in temperature gradient. The fact that the ground is covered with snow for a long period in the northern portions of the belt, and for only short periods in the south, is an important secondary factor in producing the great winter contrasts in temperature.

In the greater part of the continental province precipitation is moderate, twenty to forty-five inches, with a maximum in the warmer half of the year, but with some rainfall in all months, a large portion being snow in the winter months. The precipitation occurs largely along the warm and cold fronts of cyclones, but in summer convection is also important, and there are frequent summer thunderstorms in the southern quadrants of slow-moving low pressure areas. Convection and the greater moisture content of warm air result in spring or summer maxima of precipitation despite the greater frequency of cyclones in winter. Because of the small loss of moisture during the winter and because the maximum of moisture falls during the growing season, the rainfall is generally sufficient for crop growth, and the climate is classed as humid in spite of the limited precipitation in western, and especially northwestern, portions.

The Warm, Humid, Continental Climate of the United States (ICw)

Northward from the humid subtropical province of the Gulf and South Atlantic States is an extensive and agriculturally highly important region which has an intermediate humid continental climate of the long summer subtype. This region is bounded on the south by the isotherm of 43° for the coldest month. Its northern limit is determined by the requirement that not more than three months have a mean temperature less than 32° and not more than six months less than 50°. On the west this climatic type meets the Great Plains (IS climate) near the 100th meridian in a transition zone that extends from northeastern Texas across Oklahoma, Kansas, and Nebraska, and into southeastern South Dakota. It extends eastward into the eastern parts of North Carolina, Virginia, Pennsylvania, and New York, where it meets the coastal region having a modified continental climate (ICm). This defines a belt in which the length of the growing season increases from about 140 days at the northern border to 220 days at the southern border. The belt is about 1,200 miles long and 600 to 700 miles wide. The southern portion forms the northern part of the Cotton Belt of the United States. The northern portion chiefly comprises the great corn and winter wheat region. Large parts of Tennessee, Kentucky, and Virginia represent an agricultural transition zone between the cotton region and the corn and wheat region in which tobacco is the main crop. For purposes of description, the province may be separated into a southern, or cotton and tobacco region, and a northern, or corn and wheat region. It should be noted, however, that corn is grown extensively throughout the province.

Temperature in southern half

In the southern part of this long-summer subtype the winters are brief and mild, the average temperature of the coldest month lying between 32° and 43°; but there are occasional cold waves attended by below-zero temperatures. Summers are long and hot, with a July average of 76° to 82°. The daily range is small for a continental type of climate, mostly 16° to 20° during July and August, except in Oklahoma, where it is slightly higher. As a re-

sult, the nights are often disagreeably warm. The average relative humidity is moderate, 60% to 70%, but muggy, enervating weather is not uncommon in the summer months. The highest temperatures of record are about 105° east of the Mississippi River and 110° west of the Mississippi in a region of somewhat lower humidities.

Temperature in northern half

This is the main corn and winter wheat region of the United States. Here the climate is typically continental in character, except that it is slightly modified by marine influences in a narrow strip that borders Lakes Michigan, Erie, and Ontario. There are three months (December, January, and February) of severe winter weather; there are definite spring and autumn seasons, each of two or three months' duration, and a hot summer of three or four months. The mean temperature of the coldest month (usually January, but in a few places, February) is between 20° and 30° over most of the area. There are normally from one to fifteen days of zero weather per winter, and 100 days or more in which the temperature falls below freezing. The zero temperatures often occur in connection with cold waves, when an active cyclone with tropical maritime air on its eastern side is closely followed by a polar continental air mass.

Spring in this area is a short and uncertain season. Wintry conditions usually continue well into March and then frequently change suddenly to warm weather that starts spring growth. Such warm spells are usually of short duration and are followed by invasions of polar air from the still wintry regions of northern Canada. They continue at intervals through April, sometimes attended by snow. The average date of the last killing frost in spring ranges from about April 10 in the southern portions of the region to about May 10 in some northern portions. There is great variability from year to year, however. At Des Moines, Iowa, the date of last killing frost has varied by two full months, from April 1 in 1906 to May 31 in 1889. On the average, temperatures increase rapidly during March and somewhat less rapidly during April. The last day of March averages 10°–15° warmer than the first day.

In contrast to the spring season, autumn is long and pleasant.

ICw *Climate of the United States*	*Mean Temperature, °F.*				*Av. Precip. (Inches)*			*Snow-fall (Inches)*	*Rel. Hum. %*	*Sun-shine %*	*Number of Days*			
	Yr.	*Jan.*	*July*	*No. Months above 50°*	*Year*	*Wettest Month*	*Driest Month*				*.01 in. or more*	*90° or above*	*32° or below*	*Grow-ing Season*
Southern Portion														
Oklahoma City, Okla.	60	38	81	8	31.57	May 4 98	Feb. 1.05	8	69	66	82	59	71	220
Wichita, Kansas	56	32	79	7	30.24	May 4.57	Jan. 0.74	14	68	68	86	48	96	196
Little Rock, Ark.	62	42	81	9	47.70	April 5 12	Oct. 2.76	5	71	63	107	50	39	241
Nashville, Tenn.	60	39	79	7	46.68	March 5.15	Oct. 2.53	8	70	60	123	38	57	211
Louisville, Ky.	57	35	79	7	42.84	March 4.33	Oct. 2.69	14	68	58	124	32	68	194
Raleigh, N. C.	60	42	78	9	46.11	Aug. 5 56	Nov. 2.29	8	72	61	123	31	50	223
Northern Portion														
Omaha, Nebr.	51	22	77	7	27.77	June 4.56	Jan. 0.70	27	68	63	97	29	121	185
Davenport, Iowa	50	22	76	7	32.56	June 4 24	Dec. 1.49	27	72	59	113	20	123	178
Indianapolis, Ind.	53	29	76	7	40.14	June 3.98*	Feb. 2.60	21	70	57	133	19	100	187
Columbus, Ohio	52	29	75	7	36.19	July 3.55	Oct. 2 46	24	72	54	139	18	107	184
Pittsburgh, Pa.	53	31	74	7	35.91	July 4.16	Nov. 2 33	33	71	49	150	15	100	181
Ithaca, N. Y.	47	25	71	6	33.68	July 3.66	Feb. 1 89	55	74	45	156	9	138	158

*March, 3.89.

Summer temperatures cease after the middle of September, and thereafter the average temperatures fall steadily. Killing frosts occur during October, but there are as yet no accumulations of very cold air in Canada, and polar air masses do not bring unseasonably low temperatures. Wintry conditions are approached gradually, and often do not become severe until well into December. October is warmer than April, and November is warmer than March.

The summers are marked by alternating periods of moderate temperature and high temperature—each ordinarily only a few days in length—but there are occasional hot, dry periods of greater length. July mean temperatures are 70°–80°, and August temperatures average only 1° or 2° lower. A maximum temperature of 95° or above is to be expected annually, and in the western half the highest temperature of the year is frequently above 100°. Maximum temperatures are somewhat higher, and minimum temperatures somewhat lower in the western portions of the belt than in eastern portions; but since humidity averages somewhat lower in the west, at times both of very high and very low temperature, sensible temperatures are no more severe than in the east. Hot, dry weather, borne by tropical continental air masses from the southwestern dry areas, is more frequent in the west; oppressive, muggy days with tropical maritime air are more frequent in the east.

Average monthly temperatures decrease from south to north, markedly in winter and moderately in summer, but mean annual maxima show little relation to latitude; just as high temperatures occur in the northern portion of the region as occur in the southern portion, but there are more days of hot weather in the south. Mean annual temperatures vary from about 57° in southern Indiana to 47° in New York. Annual ranges are least in the southeast and greatest in the northern prairie area in Nebraska and Iowa. The difference is largely due to lower winter temperatures in the center of the continent. The July mean is 77° at Lynchburg, Virginia, and at Omaha, Nebraska, but the January mean is 37° at Lynchburg and 22° at Omaha. Thus the annual ranges are 40° and 55°, respectively. Sunshine averages 60% to 70% from Illinois westward, and from 50% to 60% from Indiana eastward.

Rainfall in southern half of the province

The mean annual rainfall of this region is forty to fifty inches, except that from the eastern boundaries of Oklahoma and southern Kansas the amount decreases rapidly westward to about thirty inches at the western border of the province. Rainfall is mostly well distributed throughout the year, but the maximum usually occurs during the spring; in the extreme eastern portion, however,

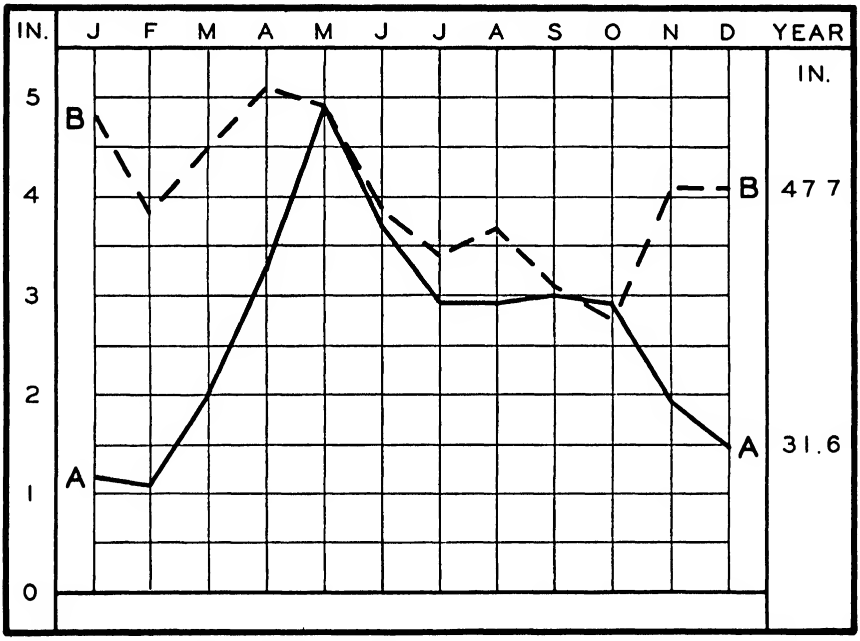

FIG. 54—Average Precipitation. Warm humid continental climate of the United States.

A. Oklahoma City, Oklahoma. B. Little Rock, Arkansas.

the greatest amounts usually fall in late summer. (See Raleigh, Fig. 55.) Except in the extreme west the minimum occurs in the autumn. Both rainfall and temperature are largely responsive to the movement of cyclones and anticyclones across or near these states. Cyclones that move from Texas or Oklahoma eastward or northeastward to the Atlantic coast are attended by warm, moist tropical Gulf air and by general rains over the entire Cotton Belt.

In winter the cyclones are well-developed, and are frequently followed by anticyclones with polar Canadian air on their front, bringing clear cold weather. In summer the cyclones are less ac-

tive, but tropical maritime air moves inland toward the heated interior—a monsoonal effect—and many thunderstorms develop. The winter rains are cyclonic, and the summer rains are partly cyclonic and partly convectional. The number of thunderstorms per year is forty to sixty. Hurricanes that reach the Atlantic or Gulf

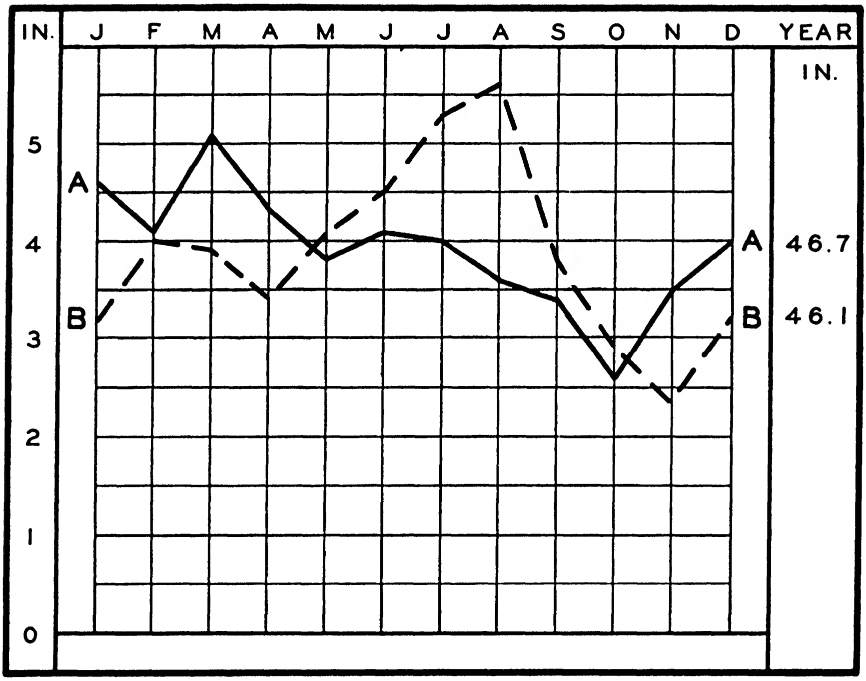

FIG. 55—Average Precipitation. Warm humid continental climate of the U. S.
A. Nashville, Tennessee. B. Raleigh, North Carolina.

coasts are usually attended by heavy rain in the southern states, and account in part for the late summer maximum in the eastern portion. Snowfall, which is generally less than ten inches a year, except in the more elevated portions, is unimportant in these states.

Rainfall in northern half of the province

Mean annual rainfall ranges from twenty-five inches in eastern Kansas and Nebraska to forty-five inches in parts of Pennsylvania and New York, and to sixty inches in some situations in the Appalachian Mountains. In general, there is more rain during the warmer half of the year than during the colder half, but the

months of maximum and minimum rainfall are variable. (See table and Fig. 56.) West of the Mississippi River, the Great Plains type of rainfall prevails, with a distinct maximum in May

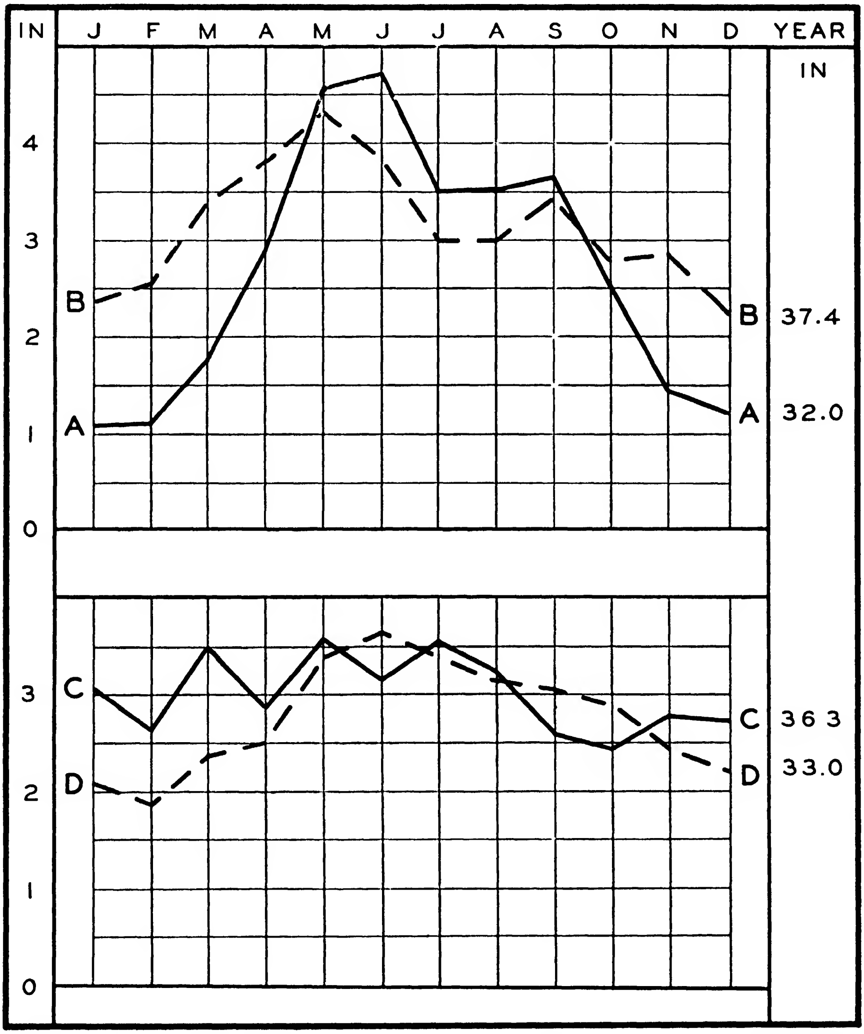

FIG. 56—Average Precipitation. Warm humid continental climate of the U. S.
A. Des Moines, Iowa. C. Columbus, Ohio.
B. St. Louis, Missouri. D. Ithaca, New York.

or June and with a minimum in January; the wettest month has three to six times as much rain as does the driest month. In the Ohio Valley, north of the river, the maximum is still in May or June, but the monthly distribution is much more even; the wettest

month is not as wet as in the west, and the driest month is much wetter. The month of minimum is usually February, and the amount is from one-half to two-thirds of the amount in the wettest month. In Pennsylvania and New York there is frequently a maximum in July.

Throughout this northern half of the province snow falls in all months from November to April. The average annual amount is about twenty to thirty inches from Nebraska to Ohio, forty to fifty inches in Pennsylvania, and seventy inches or more in parts of New York. Over most of the area snow lies on the ground for thirty to sixty days a year.

There is a large variation in monthly and annual amounts of rain in different years. The greatest percentage variation and the greatest injury by droughts occur in the western portion of the region. From the eastern portions of Kansas and Nebraska to Ohio is a great area in which corn and winter wheat are the predominant crops and in which there is also a large acreage of oats. The climate of these states is well adapted to these crops. Spring rains are normally sufficient to mature the wheat and other small grains. July and August have longer dry spells favorable for harvest, but also in the average year have sufficient rainfall and abundant sunshine to maintain the growth of corn. Occasional droughty summers greatly reduce the corn yield, especially in Iowa, Kansas, and Nebraska. When such dry summers occur, they often come in a series of several consecutive years. The growing season is normally long enough for maturing corn, but there are frequent losses of some corn in northern parts of the area by early autumn freezes, for the length of the growing season, like the temperature and the rainfall, is greatly variable from year to year.

The Cold, Humid, Continental Climate of the United States and Canada (ICc)

Northward from the northern border of the great corn and winter wheat region of the United States, the summers continue to become shorter and the winters longer and colder. The growing season becomes too short to mature corn and winters too severe for fall-sown grains, and we enter a region devoted to spring wheat in the extreme west, and to hay and pastures eastward. On the west this climatic type meets the Great Plains in the Dakotas and in western Canada; on the east it extends to the western parts of

Maine and New Brunswick, and on the north it merges into the subarctic, taiga lands of central Canada. In the United States it includes an eastern strip of the Dakotas, and all of Minnesota, Wisconsin, and Michigan, except for a strip about fifty to seventy-five miles wide along the southern border of these states. It includes northeastern New York, and some northern parts of Vermont, New Hampshire, and Maine. In Canada small portions of Alberta and Saskatchewan are included, as are also Manitoba from Lakes Manitoba and Winnipeg southward (south of latitude 51°), and southern parts of Ontario and Quebec.

The north and south boundaries are determined by the following criteria: there are either four or five months with mean temperatures below 32°, and also four or five months averaging warmer than 50°. The growing season varies from about ninety to 140 days. In general, the winters are snowy and severe; there is a rapid rise in temperature during a short spring, followed by a short warm summer and a delightful autumn. In late autumn or early winter there is often a period of mild weather known as *Indian summer.* For most of the year the air is bracing and exhilarating. Almost the entire region is popular as a summer resort because of the moderate temperatures and the presence of forests, mountains, and thousands of lakes.

This is a region of great cyclonic activity. Traveling barometric depressions, separated by moving anticyclones, pass from west to east across the Great Lakes, the New England states, and the St. Lawrence Valley with greater frequency than anywhere else in the Northern Hemisphere. The region is thus subjected to a succession of rapid changes from tropical to polar air masses. Changeableness of the weather is a marked characteristic; alternations of warm and cold and fair and stormy weather occur every few days. This is especially true in winter, when only an occasional stagnation in the movement permits settled weather for a few days. Cyclones are less frequent in summer, and there are occasional quiet periods (especially hot, dry periods) of considerable length. Blizzards and cold waves, previously mentioned in connection with other climatic types in the United States, are also of frequent occurrence in this intermediate continental type.

Because of the persistence of high pressure over northwestern Canada and of low pressure from northeastern Canada to Iceland, westerly winds predominate in winter; these winds are mostly

northwest winds in the western half of the area, and west or southwest winds in the eastern half of the area. During the summer months, southerly winds blowing out of the subtropical high and into the low over northeastern Canada prevail over almost the entire area. Mean annual temperatures range from about 35° in Saskatchewan and Manitoba to about 45° along the southern border of the province (see tables). January mean temperatures range from somewhat below zero in Manitoba to about 20° in some eastern localities. July means are highest in Minnesota and Wisconsin, and are lowest along the shores of the Great Lakes. Average annual rainfall increases from less than twenty inches in western Canada to more than forty inches in the Province of Quebec.

Spring wheat region

From the western half of Minnesota and from eastern Manitoba, the spring wheat area extends westward into the Great Plains. It is a region of very cold winters and short hot summers, with an uncertain growing season ranging from eighty to 150 days. In northern portions there is danger of frost in any month. Minimum temperatures fall below —50° in winter, and summer temperatures occasionally exceed 100°. The difference between January and July means is as much as 70°. There are several reasons for this large annual range of temperature: the region is in the center of a continent (the large cold land masses to the north of it are of special significance); because of the high latitude there is a large difference between winter and summer insolation—about eight hours in winter and sixteen hours in summer; snow lies on the ground for a considerable period in winter, and reduces the average winter temperatures.

Rainfall averages from eighteen to thirty inches, about 75% of which falls between April 1 and September 30 (Fig. 57). As in the Great Plains, June is normally the wettest month, and January or February the month of least precipitation. The region is an undulating prairie and before it was cultivated it had a native cover of prairie grasses. In the Canadian portions, under the influence of the long summer days, wheat matures in about 100 days. In Minnesota and the Dakotas, with a somewhat longer growing season, oats and potatoes are also important crops.

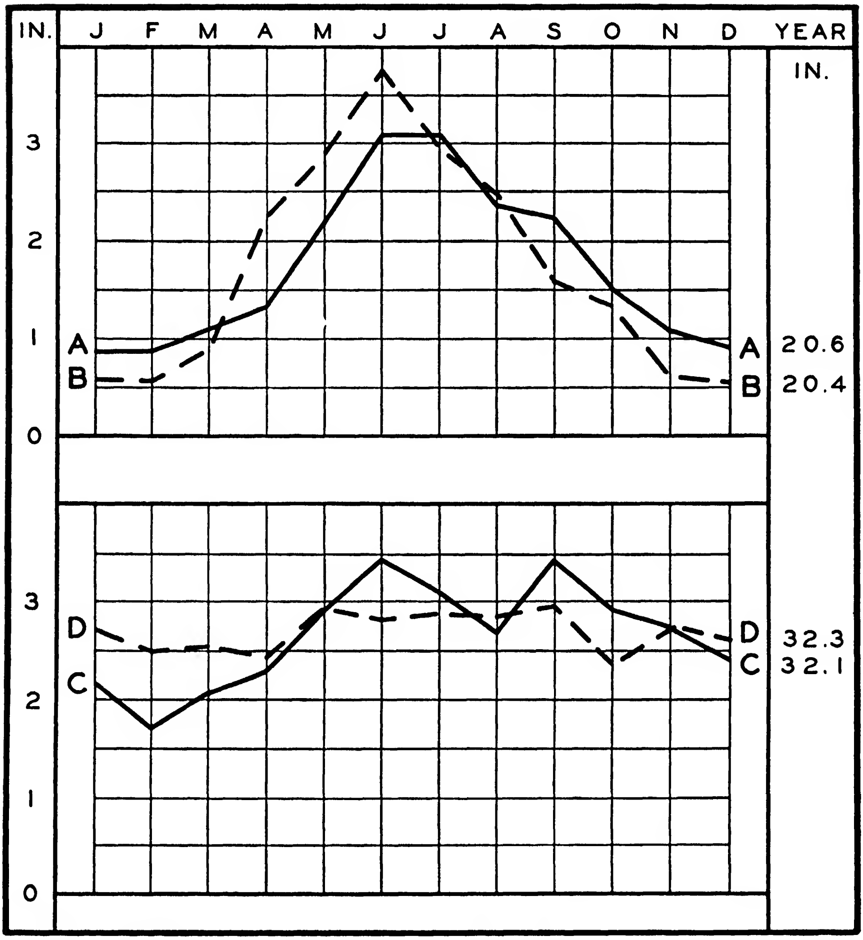

Fig. 57—Average Precipitation. Cold humid continental climate of North America.
Spring Wheat Region:
A. Winnipeg, Manitoba. B. Huron, South Dakota.
Great Lakes Region:
C. Marquette, Michigan. D. Toronto, Ontario.

The Great Lakes region

A striking feature of the climate in the vicinity of the Great Lakes is the influence exercised by these lakes, particularly upon the mean temperatures and the average length of the growing season. Since winds are prevailingly from a westerly direction, the eastern shores of the Lakes are most affected, but the influence is felt in a narrow strip on the western shores. In eastern Wisconsin the proximity of Lake Michigan has a marked effect on the tem-

ICc *Climate of United States (West to East)*	*Mean Temp., °F.*				*Av. Precip. (Inches)*			*Snowfall (Inches)*	*Rel. Hum. %*	*Sunshine %*	*Number of Days*				
	Yr.	*Jan.*	*July*	*Range*	*Yr.*	*Wettest Month*	*Driest Month*				*.01 inch or more*	*90° or above*	*32° or below*	*0° or below*	*Growing Season*
Moorhead, Minn.	40	4	69	65	22.87	June 3.88	Jan. 0.69	38	78	58	107	9	174	57	138
Minneapolis, Minn.	45	13	72	59	28.45	June 4.35	Feb. 0.97	42	72	55	108	10	147	32	166
Madison, Wis.	46	17	72	55	31.57	June 3.91	Feb. 1 46	38	75	53	107	5	142	20	174
Alpena, Mich.	42	18*	66	48	30.38	June 3.30	Feb. 1.64	67	80	46	150	3	161	16	141
Sault St. Marie, Mich.	40	14	63	49	29.62	Sept. 3.41	Feb. 1 35	73	80	45	155	1	168	31	137
Canton, N. Y.	43	16	68	52	35.56	July 3 61	Feb. 2.28	72	.	47	162	3	162	29	146
Burlington, Vt.	45	19	70	51	32.28	July 3.84	Feb. 1.58	67	..	44	147	3	146	18	162

* February.

ICc *Climate of Canada* (*West to East*)	*Mean Temp., °F.*				*Av. Precip. (Inches)*			*Snowfall (Inches)*	*No. of days .01 inch or more*
	Year	*Jan.*	*July*	*Range*	*Year*	*Wettest Month*	*Driest Month*		
Qu'Appelle, Sask.	34	0	64	64	18.59	June 3.46	Dec. 0 75	55	101
Winnipeg, Man.	35	−3	67	70	20.59	June 3.08	Feb. 0.84	48	106
Port Arthur, Ont.	36	6	63	57	22.53	July 3.62	Feb. 0.63	36	99
Parry Sound, Ont.	41	14	67	53	38.92	Dec. 4.54	April 2.25	122	145
Toronto, Ont.	45	22	69	47	32.33	Sept. 2.96	Oct. 2.43	63	150
Montreal, Que.	42	13	70	57	40.65	Jan. 3.75	April 2.51	120	156
Quebec, Que.	38	10	67	57	42.06	July 4.07	April 2.40	127	162

perature in a narrow belt near the shore, but the effect diminishes rapidly with distance inland and becomes inappreciable beyond approximately thirty miles. In western Michigan on the eastern shore of the Lake, the effect is still greater, and winter temperatures are sometimes 20° to 30° higher near the Lake than in the interior of the state. On the other hand summer temperatures are often decidedly lower. Hot, dry southwest winds sometimes reach the western shore of Lake Michigan, but by the time they have crossed the Lake, they are refreshing winds of moderate temperature and moderate humidity.

The following comparison of Green Bay, Wisconsin, and Ludington, Michigan, illustrates these differences.

	Mean Temp.		*Average Number of Days*			
	Jan.	*July*	*Growing Season*	*90° or above*	*32° or below*	*0° or below*
Green Bay	16	70	157	6	152	22
Ludington	23	67	171	1–	134	4

In upper Michigan the growing season is at least a month longer along the southern shore of Lake Superior than in the interior. On the northern shore of Lake Superior, Port Arthur, Ontario, has a January mean temperature of 6°; on the southern shore at Marquette, Michigan, the January mean is 16°. The portion of southern Ontario east of the Lakes enjoys their moderating effects. The peninsula of Ontario between Lake Huron and Lakes Erie and Ontario is especially favored—so much so that the extreme southern portion along the shore of Lake Erie is included in the long-summer type. The remainder has a climate like that of Lower Michigan. The January mean temperature at Toronto is like that at Omaha, and the July mean is similar to that along the immediate coast of southern California. As a result of these lake influences, there are fruit belts along the lake shores in southern Ontario, and, on the American side, from Michigan to New York. These belts have a growing season of 150 days or more, and they successfully produce apples, plums, peaches, and grapes. Apples extend eastward along the St. Lawrence River to the vicinity of

Montreal. The horticulturally favorable climatic elements resulting from the presence of large water surfaces are the cool, backward springs, delaying blossoming, and the long mild autumns. permitting ripening.

The annual rainfall in the Lake Region is twenty-five inches to thirty-five inches for the most part. In Minnesota and Wisconsin there is a pronounced maximum in the early part of the growing season, and a minimum in winter. From Michigan eastward the distribution is more nearly uniform, often with a primary or secondary maximum in September (see tables and Fig. 57). At Minneapolis the difference between the wettest and driest months is 3.38 inches; at Toronto, with a greater annual total, the difference is only 0.53 inch. The variation in the annual amounts from year to year is also small in the vicinity of the Great Lakes. Snowfall is heavy throughout the region, but especially on the lee side of the lakes. Annual amounts average about thirty-five inches in southern Wisconsin, forty to ninety inches in lower Michigan, more than 100 inches in upper Michigan near Lake Superior, and eighty to 100 inches in most of Ontario. The average annual number of rainy days is moderate, ranging from about 100 to 150. The average sunshine is in the neighborhood of 50%, rising to 60% or 70% in spring and summer, and frequently falling below 30% in winter. It is a region of long, bright, sunny summer days, and short, dark, cloudy, winter days. The winter cloudiness equals that of Oregon and Washington, but in summer the cloudiness is similar to that prevailing in the Mississippi Valley. Springs are short and fickle; autumns are long and pleasant, and there is frequent "Indian summer" weather.

The entire area from eastern Minnesota eastwardly to the Atlantic Ocean was originally covered with forests. There were large areas of such hardwoods as oak, hickory, and maple, particularly in the southern portions of the area, and large areas of pine and spruce in the northern portions. Much of the forest has been removed, and mixed farming is practiced in the Lake Region, with dairying the predominant agricultural activity. Hay, pastures, wheat, oats, and potatoes are grown. Wisconsin is the center of the dairying industry, and is the leading state in the manufacture of cheese. Minnesota is first in the production of creamery butter. This predominance of the dairy industry is a climatic response. The

climate is too cool and humid for advantageous production of wheat and corn, but it is excellent for hay, pastures, and oats.

Lower St. Lawrence Valley

The Valley of the St. Lawrence below Montreal is a level or rolling, fertile plain with much good farming and grazing land. The chief crop is oats, and dairying is extensively carried on. The growing season is 110 to 150 days; the winters are more severe than in southern Ontario, but not as severe as in northern Min-

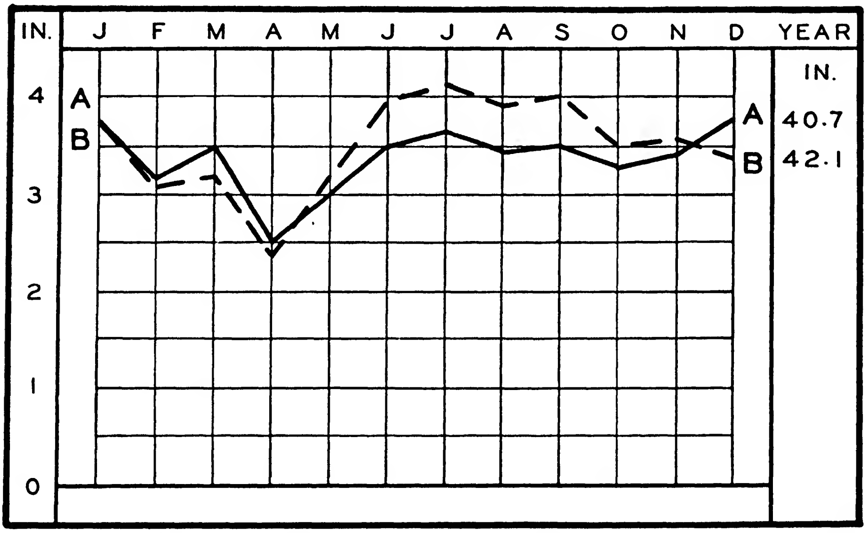

Fig. 58—Average Precipitation. Cold humid continental climate of the St. Lawrence Valley.

A. Montreal, Quebec. B. Quebec, Quebec.

nesota. Montreal has the same January temperature as Minneapolis, and Quebec is warmer than Moorhead in winter. The spring is short, and manifests frequent alternations of warm and frosty weather. The summers are very moderate, with mean maximum temperatures in July about 75° to 78°, and mean minima mostly under 60°. Maxima above 90° occur occasionally. Fine, pleasant autumns last for six to eight weeks, and zero temperatures do not occur until the latter part of November. Snow lies on the ground after December 1, and the total annual snowfall is eighty inches or more. The annual rainfall is thirty-five to forty inches (Fig. 58). The winter cloudiness is somewhat less than in the Lake Region, but the summer cloudiness is greater.

The Modified Humid Continental Climate of Eastern United States and Canada (ICm)

Because of the general drift of air from west to east, continental influences extend to the east coasts of continents in middle latitudes, and there are no intermediate marine climates on east coasts corresponding to the west coast humid marine type. Instead, there is a continental type of climate somewhat modified by the proximity of the ocean. In North America we find such a modified continental climate in a narrow coastal region extending from Virginia northward to southern Newfoundland. On the west this subtype merges into the two distinctly continental subtypes already discussed in this chapter. It is distinguished from them by a reduced annual range of temperature (36°–46°), due mainly to less severe winters, and by increased winter precipitation resulting in heavy snow in the northern half of the area (see table and Fig. 59).

From Virginia to New York the marine influence is slight and penetrates only a short distance inland. The climate of the narrow coastal belt differs from that of the interior in having somewhat higher mean annual temperatures and lower mean annual ranges of temperature, due in the main to less severe winters and fewer days of freezing temperatures. This modified continental subtype includes all of New England, except for some northern portions of Vermont, New Hampshire, and Maine. A feature of the New England region is the remarkably uniform distribution of rainfall through the year; the summers are drier and the winters wetter than in the interior. Note that at Boston the extremes occur in succeeding months, August and September, and the range is from 3.74 to 3.04. During the warmer half of the year, April 1 to September 30, Boston receives a total rainfall of 20.10 inches and Omaha receives 21.75 inches; the annual total at Boston, however, is more than thirteen inches greater than at Omaha. The difference between the driest and wettest months is less than one inch at many stations in New England. The annual precipitation is about forty inches, including an annual snowfall of forty-five to seventy-five inches.

Along the coastal plain from Virginia to Massachusetts, the even rainfall regime is favorable for hay and pasture, and dairying

is an important industry both because of climate and because of nearness to large cities. For the same reasons truck farming is of great importance. Vermont, New Hampshire, and interior Maine are hilly and mountainous, with little flat land and with much of the area 2,000 feet above sea level. The climate therefore has the local variability and the local valley nocturnal inversions of temperature which are characteristic of mountain climates, but means

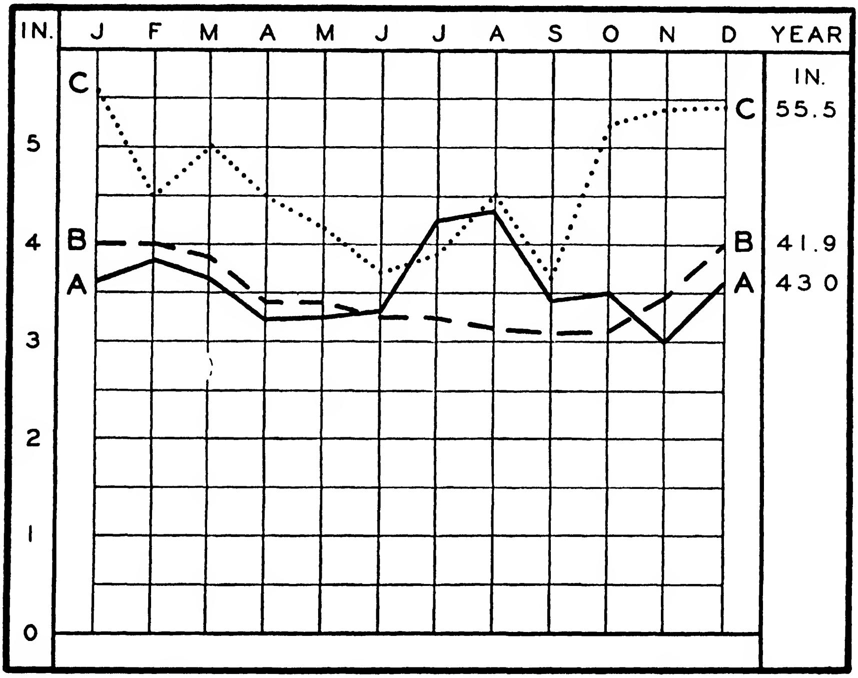

FIG. 59—Average Precipitation. Modified humid continental climate of North America.

A. New York, N. Y. B. Portland, Maine. C. Halifax, Nova Scotia.

and extremes of temperature both winter and summer are not greatly different from those of the lower St. Lawrence Valley to the north. The winters are long and cold and minima below —40° have been recorded; spring prevails for five or six weeks from about mid-April to mid-May. The summers are cool but with occasional maxima above 100°, and there are six to seven weeks of delightful autumn weather in September and October. The growing season is ninety to 160 days, permitting mixed farming and dairying. Hay, forage, and oats are the principal crops, except that potato growing is the leading agricultural industry in Maine.

ICm *Climate of North America*	*Mean Temp., °F.*				*Av. Precip. (Inches)*			*Snow-fall (Inches)*	*Rel. Hum. %*	*Sun-shine %*	*Number of Days*			
	Yr.	*Jan.*	*July*	*Range*	*Year*	*Wettest Mo.*	*Driest Mo.*				*.01 inch or more*	*90° or above*	*32° or below*	*Grow-ing Season*
Baltimore, Md.	56	35	78	43	42.69	Aug. 4.64	Nov. 2.75	23	68	58	124	22	72	187
New York, N. Y.	52	31	74	43	42.99	Aug. 4.33	Nov. 2.96	33	70	60	126	6	92	209
Boston, Mass.	50	28	72	44	41.05	Aug. 3.74	Sept. 3.04	44	72	57	125	9	106	193
Portland, Me.	46	22	68	46	41.94	Feb. 4 00	Sept. 3.10	73	74	57	133	2	133	181
Eastport, Me.	42	21	60	39	39.39	Jan. 3 92	Sept. 2.78	74	79	49	145	*	139	177
Halifax, N. S.	44	23	65	42	55.52	Jan. 5.59	Sept. 3.55	77	..	..	167	..	...	...
St. Johns, Nfld.	40	23	59	36	53.77	Nov. 6.06	June 3.55	96	..	..	169	..	...	...

* Less than 1.

Along the coast of Maine, and in Nova Scotia, New Brunswick, and southeastern Newfoundland, the marine influence results in a milder and more equable climate than that just described. The winters are less severe, the summers are cooler, and the growing season a month longer than in the interior. The seasons are delayed one or two weeks by the ocean influence, February having about the same temperature as January, and August about the same as July in many places. January temperatures at Portland and Eastport, Maine, and at Halifax, Nova Scotia, are higher than those at Des Moines, Iowa, and summer temperatures are higher than at San Francisco. Annual precipitation amounts to forty to sixty inches. On the coast of Maine it is evenly distributed through the year. In New Brunswick and Nova Scotia and at St. Johns, Newfoundland, there is a winter maximum and a spring or summer minimum. The annual snowfall is seventy to 100 inches.

This maritime region has frequent gales, which are associated with the passage of many cyclones. Gales are especially frequent during the winter months, but the average wind movement is rather disagreeably high throughout the year. Most of the coastal portion is also subject to dense fogs, especially during the summer months. They are most frequent on the Atlantic coast of Nova Scotia. They occur with southerly or southeasterly winds, which carry warm moist air from the Gulf Stream over the cold coastal waters found along these shores. In New Brunswick lumbering is the chief industry, but wheat, oats, and buckwheat are grown, as is forage for sheep and cattle. In Nova Scotia fishing and lumbering are the main occupations, but dairy farming is important, and this province produces some apples and peaches.

CHAPTER XIV

Polar and Subpolar Climates of North America

On the north the spring wheat, hay, and pasture region, in which agricultural pursuits are the chief occupation, gradually gives way to a region in which cultivated crops are of minor importance and are capable of supporting only a sparse population; there are, however, extensive and valuable forests in this region. This is the taiga or subpolar climatic province, in which at least one month has a mean temperature above 50°. In the northern portion of this province the forest diminishes in density, and the trees decrease in size until there are only low shrubs and bushes. This marks the transition to truly polar climatic regions in which plant life is either reduced to lowly forms or disappears.

The Taiga Climate of Canada and Alaska (SPT)

The subpolar province of North America includes the Aleutian Islands and the greater part of Alaska, omitting the Arctic coast, the Bering Strait region, and southeastern Alaska. It extends from Alaska southeastward across Canada to Newfoundland and the southern portion of Labrador. It is widest in western Canada at about the 120th meridian, and from that meridian westward it reaches slightly north of the Arctic Circle. The reason for this northward extension is in the continental character of the climate in northwestern Canada and interior Alaska. The land heats rapidly in the almost continuous sunshine of midsummer, and raises the mean air temperature above 50° for a short season. At its eastern extremity the belt becomes narrow, the northern limit bending southward to latitude 54° because of the influence of the cold Labrador current.

This is a region of extensive coniferous forests, especially spruce and fir. On the south the trees are of moderate size, and the cover is continuous but not dense. Northward the trees become

smaller and more scattered, and they finally degenerate into brush and scrub growths with open patches of moss and bog, merging into the treeless arctic climate. The isotherm of 50° for the warmest month marks approximately the poleward limit of the growth of trees and is taken as the limit of the subpolar climatic province. This taiga type of climate is found only in North America and Eurasia, and it includes those areas in which the mean temperature is above 50° for from one to three months and below 32° for six or more months.

An outstanding feature of the climates of all regions in such high latitudes is the great contrast in summer and winter insolation, the almost continuous daylight in June and July, and the long dark nights of midwinter. At latitude 60° N. the sun is above the horizon for 18.8 hours at the summer solstice, and below the horizon an equal length of time at the winter solstice. The midsummer insolation is greater than that received in equatorial regions; the midwinter insolation at latitude 60° is about 6% of that at the equator. The natural result of these large seasonal changes in insolation is a large annual range of temperature except where marine influences prevail. The records confirm this and show that the continental interiors in the subpolar climatic zone have the largest annual temperature ranges in the world. Considerable areas from eastern Alaska to Hudson Bay have annual ranges exceeding 82°. The only greater ranges known are those in a similar situation in interior Siberia.

In these regions the summer temperatures are higher than is normal for their latitude, but the most important reason for the great difference between summer and winter is the extremely low temperatures of winter resulting from the radiation cooling of the land surface and the cooling by conduction and radiation of quiescent air masses overlying the land. Farther north, in the Arctic Ocean and along its coasts, the contrasts in temperature are less. This is because, in summer, the cold water keeps the temperature as much as 20° lower than in the interior; in winter an ice-covered ocean does not become as cold as a land surface in the same latitude, because the ice receives more heat by conduction from below. The second outstanding feature of the subpolar climate, then, is the extremely low temperatures that occur in winter. There is a record of —94° in Siberia, and of —80° in Yukon Territory.

Taiga Climate (SPT) *of Canada* (*west to east*)	*Mean Temperature, °F.*				*Highest Temp. of record °F.*	*Lowest Temp. of record °F.*	*Average Precipitation (Inches)*			*Average Snow-fall (Inches)*	*No. of days .01 inch or more*
	Year	*Jan.*	*July*	*Range*			*Year*	*Wettest Month*	*Driest Month*		
Dawson, Yukon Ter.	23	−22	59	81	95	−68	12.49	July 1.54	March 0.53	57	108
Ft. Good Hope, N. W. Ter.	14	−32	61	93	95	−79	10.24	Aug. 1.63	Jan. 0.48	52	103
Prince George, B. C.	38	13	59	46	95	−56	17.90	Aug. 1.94	Apr. 0.93	61	87
Fort Vermillion, Alb.	27	−14	60	74	98	−76	12.28	July 2.14	Feb. 0.33	30	66
Prince Albert, Sask.	33	−5	63	68	96	−70	15.40	June 2.67	Feb. 0.60	48	86
Norway House, Man.	28	−10	62	72	90	−54	17.33	Sept. 2.76	Jan. 0.69	53	97
Fort Hope, Ont.	29	−9	62	71	99	−54	15.83	July 2.78	Feb. 0.45	58	110
Mistassini Post, Que.	29	−6	61	67	95	−56	31.86	July 3.74	March 1.65	90	142
Fort Chimo, Que.	20	−16	51*	67	88	−43	28.61	July 4.32	Dec. 0.62	..	...
Belle Isle, Nfld.	31	9	52*	42	71	−27	47.59	Oct. 6.04	Feb. 2.06	103	61

* August.

Interior Canada

From Yukon Territory to western Quebec within the limits of the taiga province, the climate is essentially the same and is typically continental (Fig. 60 and table). July temperatures are about

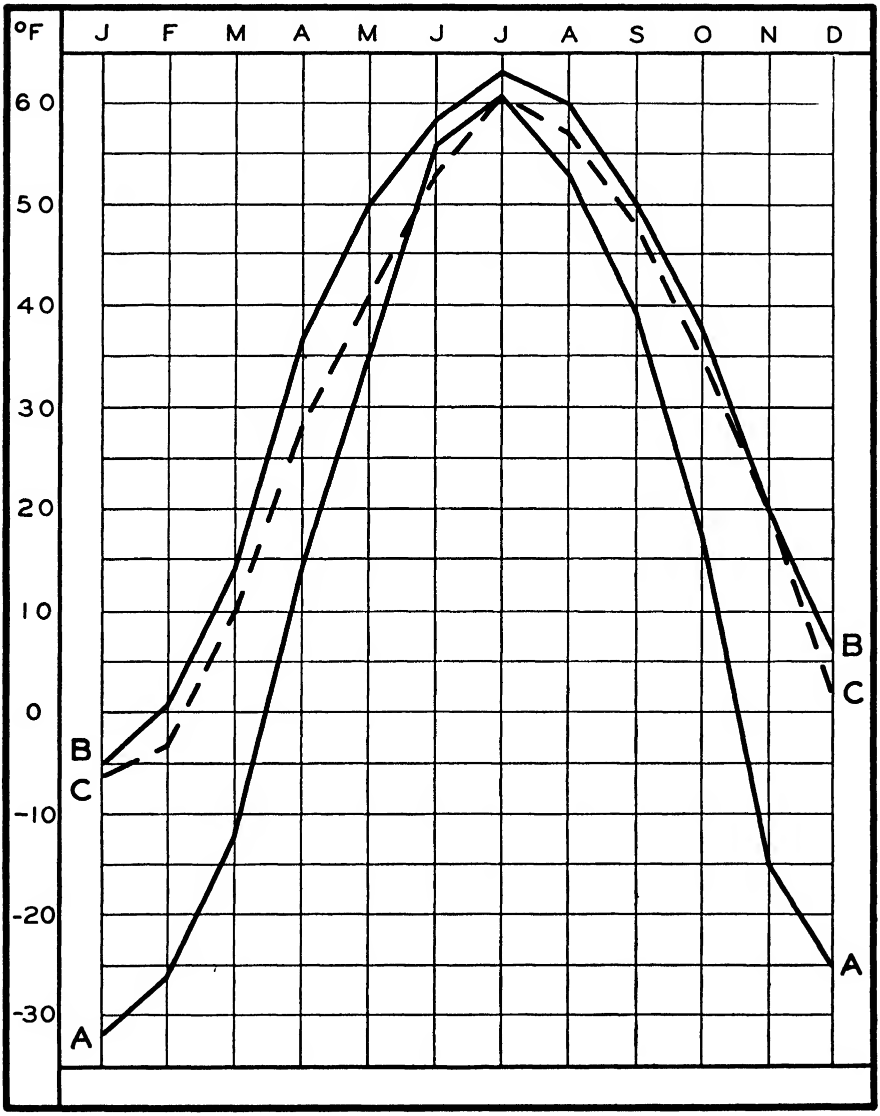

FIG. 60—Average Temperature. Taiga climate of interior Canada.
A. Ft. Good Hope, N. W. Ter. B. Prince Albert, Saskatchewan.
C. Mistassini Post, Quebec.

60° throughout (varying between 59° and 63° in the accompanying table), but summer temperatures are of short duration; only June, July, and August have mean temperatures above 50°, and on the northern border only the one month of July has such a mean temperature. At Fort Good Hope, Northwest Territories, on the Mackenzie River within a short distance of the Arctic Circle, the July mean is 61°, which is the same as the mean of the warmest month at San Francisco; but at Fort Good Hope the mean for August drops to 53°, for September to 39°, and for October to 17°; the October mean at San Francisco is 60°. Thus in the Mackenzie Valley summer changes rapidly to a very long and severe winter. Each of the five months from November to March, inclusive, averages more than 12° below zero, and the mean for January is —32°. The coldest part of the United States (omitting mountains) is northern North Dakota, where the average temperature of the coldest month is approximately zero. From March to April the mean temperature at Fort Good Hope rises 27°, but winter conditions continue into May and then change rapidly to the cool summer weather of June, with almost no intervening spring season. Dry air and light wind movement make these long-continued subzero temperatures endurable.

The remainder of this interior area has somewhat less severe winters than those of the Mackenzie Valley, but at least one month (and over most of the area two or three months) has a mean temperature below zero. There is an exception in interior British Columbia, west of the Rocky Mountains, where winter temperatures are considerably moderated by the influence of the Pacific Ocean. Note Prince George, which has a January temperature approximately equal to that at Minneapolis, although the July temperature is 13° lower than at Minneapolis. Except in the area represented by Prince George, the annual ranges of temperature are very large, varying between 67° and 93°. Maximum temperatures above 90° and minimum temperatures below —50° have been recorded almost everywhere in the region. At Fort Good Hope the highest temperature recorded is 95° and the lowest —79°, giving an absolute range of 174°. Fort Vermillion, Alberta, on the Peace River, has the same absolute range, the extremes in this case being 98° and —76°. At Mistassini Post in central Quebec a maximum of 95° and a minimum of —56° have been recorded, making the absolute range 151°.

Although high temperatures occasionally occur in midsummer, the region is subject to invasion of cold air from the ice-covered Arctic where temperatures remain low, and it is not free from the danger of frost even in July and August. Hence only hardy crops that can withstand temperatures below freezing can be grown, and for these the growing season is short. Along the southern border of the province the growing season reaches 100 days; in the Mackenzie Valley it is fifty to seventy-five days. In the colder areas the ground remains permanently frozen to great depths, and only the upper few feet thaw during the summer.

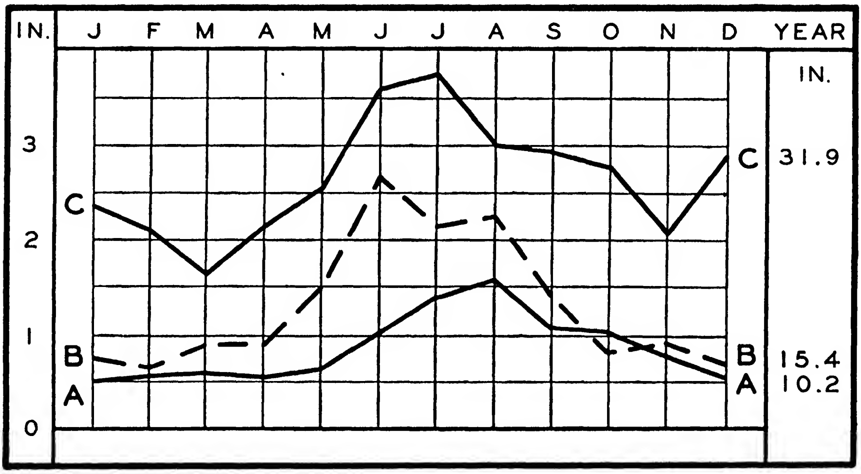

FIG. 61—Average Precipitation. Taiga climate of interior Canada.
A. Ft. Good Hope. B. Prince Albert. C. Mistassini Post.

The rainfall of this interior region is less than twenty inches, except in parts of Ontario and Quebec, and less than fifteen inches in many places (Fig. 61). In warmer regions this would signify a semiarid climate, but in this region, with only a brief period of important evaporation and with the moisture securely frozen in the soil for most of the year, fifteen to twenty inches is sufficient to keep the soil wet enough to support forests. In winter the air is too cold to contain much moisture, and is mainly dense, subsiding air attended by clear anticyclonic weather. Nevertheless some cyclonic depressions do cross the area—especially its southern portion—and from these a moderate snowfall results. The snow may accumulate to a depth of two or three feet, and may remain on the ground for five to seven months because of the absence of thawing

weather. In summer the high temperatures result in the development of relatively low pressure, inflowing moist air, and some convection. The greater part of the precipitation, therefore, occurs during the warmer months, and is largely cyclonic; an average of about five to ten thunderstorms occurs each year.

The brevity of the growing season limits the agricultural use of the land throughout the region. Spring wheat is grown in the Peace River Valley in northern Alberta, where the growing season is ninety to 100 days. Elsewhere there are scattered agricultural settlements in the river valleys where barley is grown, and also hay, potatoes, vegetables, and berries. The population is sparse, the area devoted to crops is only an insignificant percentage of the whole, and the climate permanently precludes any extensive agricultural development.

Interior valleys of Alaska

The climate of the Alaskan interior is very similar to that of the interior of Canada just described. (Compare the tables on pages 241 and 246.) July temperatures average about 57°–61°, and June and August are usually slightly above 50°. The summers are pleasant, with maximum temperatures frequently above 80° but rarely above 90°. The winters are very cold, but not so cold as in the Mackenzie Valley. There are usually two or three months with average temperatures below zero (as compared with five months at Fort Good Hope), but zero weather is not continuous during the winter. The number of days with a minimum temperature of zero or below is about 100 to 160, but is less than 100 at stations near enough to the coast to receive some marine influence. At Matanuska on the southern edge of the inland area, the temperature falls below zero on sixty days a year, and the mean of the coldest month is 7°. Here June, July, and August are usually free of freezing temperatures, giving about 100 days of growing weather. This region has the soil and climatic conditions suitable for considerable agricultural development. Farther inland, there are frequently freezing temperatures in June and again in August, and the growing season is reduced to fifty to eighty days. In the northern portion July also has freezing temperatures in many years.

Precipitation is similar to that of the Canadian taiga, mostly between ten and twenty inches, with local variations due to differences of exposure. July and August are the wettest months, and

Taiga Climate (SPT) *of Alaska*	*Mean Temperature, °F.*				*Av. Precip. (Inches)*			*Snowfall (Inches)*	*No. of days .01 inch or more*	*Length of Growing Season (Days)*
	Year	*Jan.*	*July*	*Range*	*Year*	*Wettest Month*	*Driest Month*			
Interior Valleys										
Matanuska	33	7	57	50	13.91	Aug. 2.60	March 0 48	39	83	102
Tanana	23	−16	59	75	12.47	Aug. 2 22	April 0 25	48	113	. . .
Fort Yukon	19	−26	61	87	7.28	June 0.94	Sept. 0.29	45	67	0
Southern Coastal Alaska and Aleutian Islands										
Dutch Harbor	40	32	51*	19	63.69	Oct. 9 05	July 2 39	. . .	178	133
Coal Harbor	39	28	53*	25	48 51	Apr. 5 56	June 2.44	72	. .	131
Dillingham	33	14	56	42	28.51	Sept. 4 65	Dec. 1 14	42	133	. .
Kodiak	41	29	54*	25	61.03	Oct. 7.28	July 3.38	49	. .	138
Seward	39	20	56	36	62.87	Sept. 10 10	June 2 30	80	. . .	131
Cordova	40	26	54*	28	131.55	Sept. 22.46	June 6.27	150	202	147

* Also August.

the four months, June to September, receive about half the total annual rainfall. During the winter and spring months the rainfall is light, in many places averaging less than a half inch per month. During the winter most of the cyclones from the Aleutian Low pass to the south of interior Alaska, and hence the prevailing winds in the interior are from east, northeast, or north, composed of stable polar continental air masses of small moisture content. In summer the pressure gradient is reversed, and inflowing moist maritime air masses made unstable by surface heating over the land produce considerable precipitation and occasional thunderstorms. Because of the light winter precipitation, the snowfall is not excessive, totaling about forty to fifty inches a year, which is much less than that which falls in a large part of the New England states and in the St. Lawrence Valley.

These interior valleys have a native forest cover, principally of spruce, aspen, poplar, and white birch, but the trees are small to medium in size, and the timber line is reached at elevations of 3,000–5,000 feet. There is some agricultural development in the more favorable situations in the valleys. Oats and barley are successfully grown, as are many vegetables, including potatoes, cabbage, and root crops. The grazing of caribou and reindeer is increasing. The mineral wealth of the area is large.

The Aleutian Islands and the southern coastal region of Alaska

An area which includes the Aleutian Islands, the Alaska Peninsula, the south-facing coast of Alaska, and the southern half of the west coast has a taiga climate with definite marine modifications. The area is mountainous and rough with an irregular coast line, and there is little level land suitable for even the limited agriculture that the climate permits. As compared with the interior valleys, the winters are mild, with only an occasional day with a minimum below zero. The summers are decidedly cool, but two or three months average slightly above 50°. The Pacific coast region extends inland twenty to forty miles, but there are only small areas of level land. For the most part June, July, and August have mean temperatures from 50°–56°. The January means range from 20°–30°, about the same as January in the northern half of Illinois; there are one to fifteen days of zero temperatures.

Precipitation along this coast is heavy, although in general not so heavy as in the southeastern extension of Alaska, which is included in the cool, humid marine climatic type (IM). Along the south coast the rainfall decreases from more than 100 inches at the eastern extremity to sixty inches in the west. Rainfall is moderate to heavy in all months. The minimum is in June and July, when the region is under the influence of the North Pacific high pressure area. The greatest monthly amounts are in September and October. This is the season when the winter development of the Aleutian Low begins and when the tracks of traveling cyclones are farthest north. From Kodiak Island eastward the mountains are heavily wooded to heights of 1,000 to 3,000 feet with spruce, hemlock, and some cedar. Because of its mountainous character, the region has few agricultural possibilities, but there are some small valleys suitable for stock raising and dairying. Berries and vegetables of all kinds grow in great profusion and mature without injury by frost.

The Alaska Peninsula and the Aleutian Islands have an even more distinctly marine climate. Thanks to the abnormally warm water of the Pacific Ocean, winter mean temperatures are only slightly below freezing—about the same as the January mean in central Missouri. July and August means are usually slightly above 50°. Thus the annual range of temperature is about 20°, as contrasted with a range of 50° to 85° in the interior valleys. After the first part of May there are usually no freezing temperatures until the latter part of September; this frost-free period of 125 to 135 days is greater than that in Montana, North Dakota, or most of Maine. Nevertheless, growing conditions in the Aleutian area are very different from those in the States named. The Aleutian Islands and the Alaska Peninsula have an excessive amount of cloudiness and fogginess, and even though the sun is above the horizon for seventeen or eighteen hours in midsummer, there is little sunshine. This deficiency of sunshine, together with the low summer air temperatures, makes growth very slow, and even the hardy grains and vegetables are not much of a success. The native grasses grow luxuriantly on the lower slopes of the mountains, however, and offer some grazing possibilities.

The annual precipitation ranges from sixty to eighty inches, and there is rain on about 200 days a year. The maximum rain-

fall is in the autumn and winter months, when the semi-permanent Low overlies the islands and the adjacent waters of the Pacific. The rainfall is lightest in June and July, when the Pacific High has displaced the Low. Snowfall is lighter than might be expected, and ordinarily does not accumulate to a sufficient depth to prevent winter grazing. The harbors are open to navigation all year. In marked contrast with the south coastal region, the peninsula and the islands are almost treeless, although rainfall and temperature seem to be favorable for the growth of northern coniferous forests.

The Bering Sea coast

The Bering Sea receives much cold water from the Arctic Ocean through the Bering Strait, and its waters are much colder than those of the Pacific Ocean to the south; hence the west coast of Alaska is colder than the south coast. The Alaska Peninsula and the Aleutian Islands are much influenced by the warm water of the Pacific, but north of the Peninsula the coastal region becomes rapidly colder during the colder part of the year; the temperature of the warmest month changes little, and July isotherms are nearly parallel with the coast. The January mean at Dillingham is 14° as compared with 29° at Kodiak on the Pacific side of the Peninsula. Nome in latitude 64°31′ has a January mean of 1°. The summer temperatures are governed more by distance from the coast and by local exposure than by latitude, and along the coast as far north as Nome the warmest month has a mean temperature slightly above 50°. The climate is therefore classified as a taiga climate, but the region is largely devoid of timber. This coast is non-mountainous and of low relief, and it contains the lower valleys and mouths of several rivers. The largest of these is the Yukon, which forms a large delta.

The precipitation is decidedly less than in the Pacific coastal region, and decreases northward, ranging from about thirty inches in the Bristol Bay region to about thirteen inches at St. Michael on Norton Sound, latitude 63°29′ N. The maximum rainfall is from July to October, which is the period of southerly moist inflowing winds. About half the annual total falls in these months. The winter precipitation is light because the area is north of the center of low pressure and is swept by dry polar continental air from the northeast. The gradient between the Mackenzie Valley high pres-

sure area and the Aleutian Low is steep in winter, resulting in high northerly winds and much stormy weather (but little precipitation) in the Bering Sea and in the coastal plain.

Because of the light winter precipitation, the snowfall is moderate, about fifty to sixty inches a year. The snow cover usually disappears in May and begins to accumulate again in October. The harbors are closed by ice from October to May, and floating sea ice extends southward to the vicinity of the Pribilof Islands. The time of disappearance of ice from the bays is controlled to a considerable extent by the direction of the wind. The resources of the region are mainly fisheries and minerals. Vegetation is confined largely to grasses and mosses. There is no agriculture, but reindeer husbandry is a growing industry.

The eastern maritime area

Eastern Quebec, most of Newfoundland, and the southern end of Labrador also have a subpolar climate considerably modified by marine influences, but not so much so as the Alaskan coasts and islands. The winters are fully as long as in the interior of Canada, but not nearly so severe; the summers are brief and about 10° cooler than in the interior, but one or two months have temperatures slightly above 50°. The warmest month is August rather than July, and February is colder than January in some localities (Fig. 62).

Three very different air masses influence the climate of this maritime area. Tropical maritime air from the south and southeast moving across the warm waters of the Atlantic is moderate at all seasons; polar maritime air from the northeast, which is cooled by the Labrador current, is abnormally cool in summer and moderately cold for the latitude in winter; northwest winds bring polar continental air, cool in summer and very cold in winter. Because of these combined influences, there is little real summer weather and no mean temperatures above 60°. The winters are warmer than in the interior, but occasional invasions of air from the northwest bring temperatures as low as —40° in Quebec and —10° to —25° in Newfoundland.

This is a region of frequent cyclonic storms. Most of the cyclones that cross Canada and the United States pass near or over this area on their eastward journey. Hence there are many changes in wind direction, temperature, and weather. Because of the vari-

ation in the frequency and paths of cyclonic storms, both the daily variability and the variability of the same month in different years are great. Dense advection fogs, formed by the movement of warm moist air over cold land or ocean surfaces, are of frequent occurrence

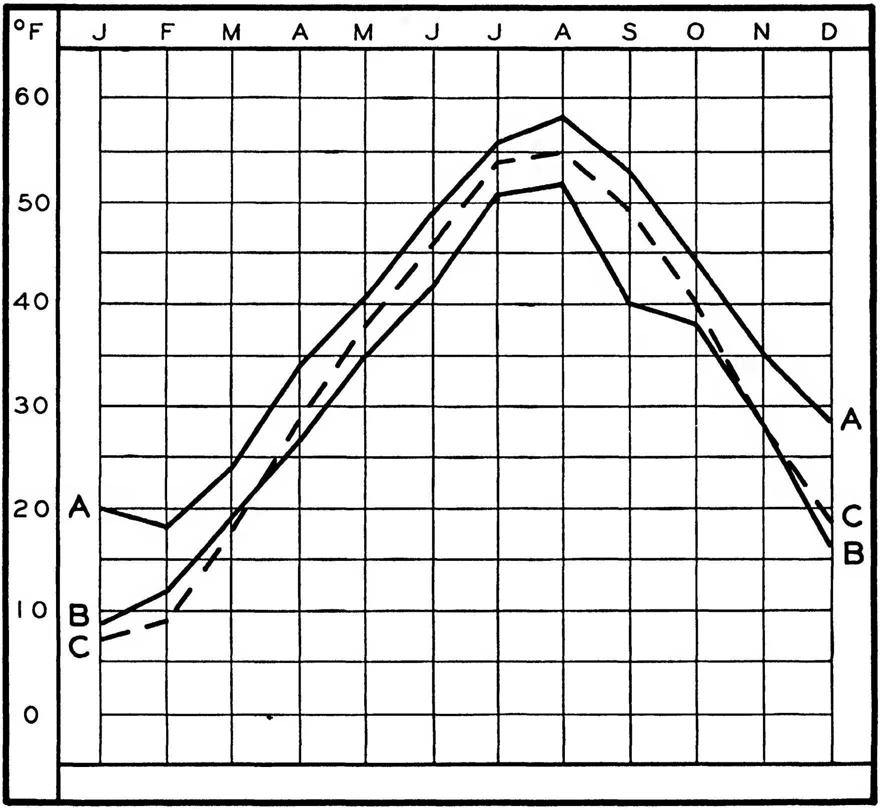

FIG. 62—Average Temperature. Taiga climate of North America, eastern maritime area.
A. Port aux Basques, Newfoundland. B. Belle Isle, Newfoundland.
C. Harrington Harbor, Quebec.

in the summer months, averaging twenty-five to forty-five a year, but even the foggiest location on the coast of Newfoundland is less foggy than the coast of Nova Scotia (see page 238).

Port Aux Basques in southwestern Newfoundland is in approximately the same latitude as are Bismarck, North Dakota, and Seattle, Washington. A comparison of the temperatures reveals interesting climatic differences among the east coast, the interior, and the west coast of North America. At Port Aux Basques only three months, July, August, and September, have average tem-

peratures above 50°, the warmest being August with a mean of 58°; at Bismarck there are five months above 50°, three months above 60°, and a mean temperature of 70° in July; at Seattle the average temperature is above 50° for six months, May to October, inclusive, but only two months, July and August, average warmer than 60°; both July and August have means of 63°. At the Newfoundland station four months have an average temperature below freezing, the lowest being 18° in February. Bismarck, with five months below 32° and with a mean of 8° in January, has a longer and colder winter. At Seattle all months are well above freezing, and the lowest monthly mean is 40° in January. The highest temperature of record is 80° at Port Aux Basques, 108° at Bismarck, and 98° at Seattle; the absolute minima are —14°, —45° and —3°, respectively. Port Aux Basques has a growing season of approximately 120 days, Bismarck 134 days, and Seattle 250 days.

At Belle Isle in extreme northern Newfoundland there is no summer, but there are two months of spring weather (July and August) which have mean temperatures of 51° and 52°, respectively; there are six months of real winter (average temperatures below 32°), the lowest mean being 9° in January. At Fort Chimo in northern Quebec on Ungava Bay, July and August barely rise above 50°, and there are eight months of freezing weather. Annual ranges throughout this eastern maritime region are small as compared with the interior, but they are large as compared with the west coast or with stations in lower latitudes.

The rainfall of Newfoundland and maritime Quebec is mostly about forty inches or more, but there are large local variations, and the amount decreases rapidly northward to about twenty inches on Ungava Bay (Fig. 63). In most places the heaviest precipitation occurs from June to October, which is the season of inflowing southerly winds from the Atlantic. In winter dry, westerly continental winds prevail, but the numerous winter cyclones bring tropical air masses, and are often attended by snow. In consequence there is moderate precipitation in the winter and spring months, and in some locations the maximum for the year falls in December or January. Hence the snowfall ranges from seventy-five to 150 inches a year, and is heavier in this region than in any other portion of North America, except in the western mountain regions and in a part of the coast of southern Alaska.

Although the summers are brief and cool, the season between

killing frosts is longer than in the interior, and crops which require little heat but a growing season of 100 days or more are successfully grown in this area. These crops are chiefly hay, oats, potatoes, turnips, and cabbages. Agricultural use of the land is not ex-

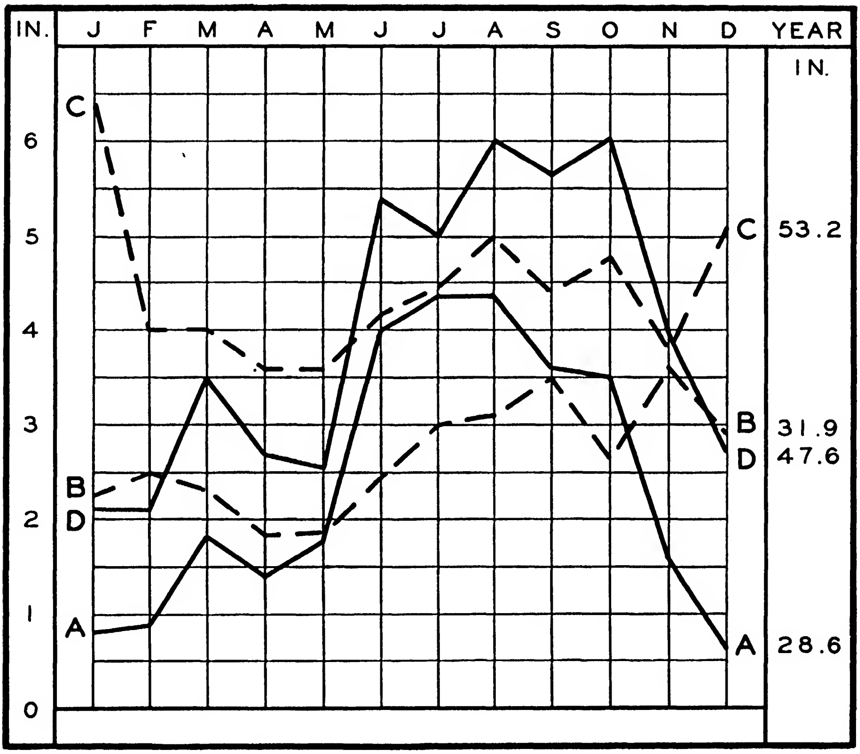

FIG. 63—Average Precipitation. Taiga climate of North America, eastern maritime area.
A. Fort Chimo, Quebec. C. Port aux Basques, Newfoundland.
B. S. W. Point, Quebec. D. Belle Isle, Newfoundland.

tensive, however. The country is heavily forested, and lumbering remains the dominant industry on land. Fishing is the stable industry of Newfoundland. On the whole this maritime climate is healthful, invigorating, and agreeable, escaping both the heat of the interior and its severe cold.

The North American Tundra Climate (PT)

The word *tundra* was originally applied in Russia to the treeless and often marshy plains that border the Arctic coast of Europe and Asia, but it has been extended to the region of similar

climatic, soil, and vegetative conditions in North America. Hence *tundra,* as a geographic term, refers primarily to the arctic plains. *Tundra* is sometimes also used to refer to the characteristic vegetation of the region, and, finally, the climate of such a region is called a *tundra climate.* In regions having a tundra climate, the mean temperature of the warmest month is below 50° but above 32°. The tundra as a geographical region may be likened to the steppe and desert regions of warmer climates because of the scantiness of its vegetation and the sparseness of the population it will support. On its southern border the tundra has areas of dwarf trees and brush, and on its northern border desert-like areas of bare rock and gravelly soil with occasional patches of grass in sheltered places. The broad central portion, the typical tundra, is the grass tundra, which is covered with an almost continuous mat of mosses, sedges, and lichens.

The North American tundra includes all of North America north of the isotherm of 50° for the warmest month, which marks with fair accuracy the poleward limit of tree growth. It thus includes those coastal plains of Alaska which border the Bering Strait and the Arctic Ocean, and the area north of a line running from the Arctic coastal plain of the Yukon Territory in a general southeasterly direction to southern Labrador. The coastal fringe of Greenland also has a tundra climate.

Within the polar circles the regular twenty-four-hour cycle of day and night ceases to exist, and there are long periods of continuous daylight with abundant insolation at one season, and long periods of darkness or semi-darkness and zero insolation at the other season. This is a climatic feature of great importance, and profoundly influences the life of the inhabitants of such regions. As the days lengthen with the approach of the summer solstice, there is a rapid transformation in the landscape of the North American tundra. The snow disappears, the ice begins to break up, herds and flowering plants spring up and grow rapidly, and by mid-summer there are great fields of flowers. Simultaneously with the awakening of the land, land and sea birds arrive in great numbers, and mosquitos and flies appear in myriads. In this season the Eskimos become very active in hunting and fishing, for they must accumulate and preserve a large part of their food supply for the long night during which there is little outdoor activity. As

the night approaches, the birds and mosquitos disappear, the soil freezes and becomes snow-covered, and the inhabitants prepare their permanent winter quarters.

Temperature

Some typical temperature curves by months are shown in Fig. 64. The first fact that will be noticed in this figure is the very great annual range of temperature at all stations except Ivigtut. This is in spite of the fact that all these stations are coastal stations. The great ranges are primarily due to the great difference between summer and winter insolation, and to the fact that ice-bound waters are not so effective as open water in moderating winter temperatures. At Ivigtut at the southern end of Greenland the influence of the open, warm water of the Atlantic is evident in the comparatively mild winter temperatures and in the reduced annual range. On the other hand, there is evidence of some marine influence even in the ice-bound Arctic; Point Barrow is 12° warmer than Fort Good Hope in January and 20° cooler in July. (Compare Figs. 60 and 64.) The most northerly station represented is Fort Conger (81° 44′ N. latitude) on Lady Franklin Bay, Ellesmere Island, where the annual range is 80° as compared with 93° at Fort Good Hope in latitude 66° 25′.

Another very evident characteristic is the rapid increase of temperature in the spring months and the only slightly less rapid fall after August or September. This rapid change is directly related to the time of the beginning of continuous day in spring and of continuous night in autumn. At Fort Conger the sun is continuously above the horizon from about April 10 to September 1, and continuously below from about October 20 to February 23. For this reason May is 28° warmer than April and October is 22° colder than September. That there is practically no insolation in February at Fort Conger, but instead a rapid loss of heat by radiation, is indicated by the fact that February is 6° colder than January. The low summer temperatures at the stations shown in Fig. 64, as compared with interior stations in similar or higher latitudes, is also evidence of the influence of nearby cold water areas. Along the Arctic coast much loose floating ice remains all summer, and on the Atlantic coast there are icebergs throughout the year.

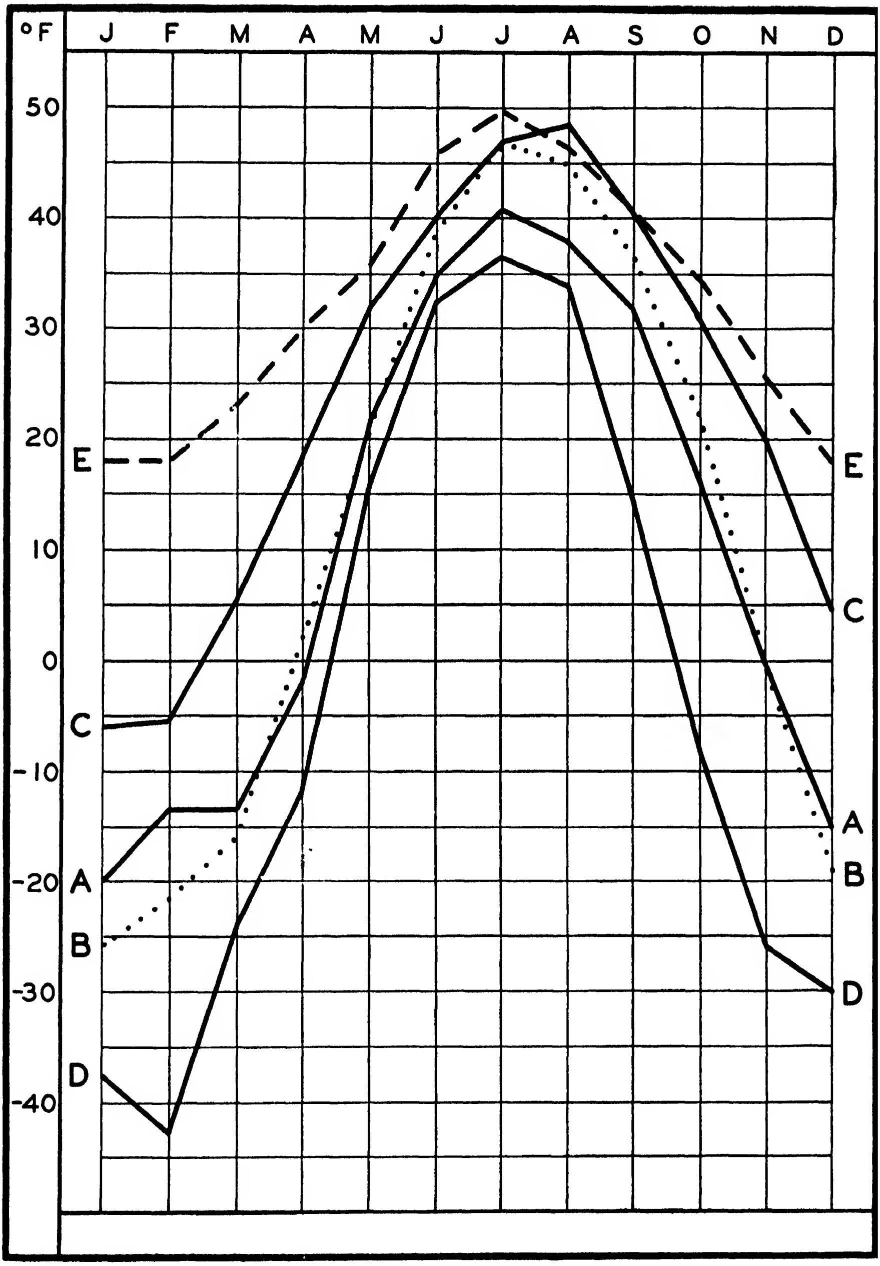

Fig. 64—Average Temperature. Polar tundra of North America and Greenland
A. Pt. Barrow, Alaska. C. Hebron, Labrador.
B. Chesterfield Inlet, N. W. Ter. D. Ft. Conger, Ellesmere Island.
E. Ivigtut, Greenland.

Precipitation

The precipitation over the greater part of the North American tundra is between ten and twenty inches. It increases to thirty inches on the west coast of Alaska, and to more than forty inches in southern Greenland. It decreases rapidly northward along the west coast of Greenland to less than ten inches at latitude 70°, and is also less than ten inches over most of the Canadian archipelago

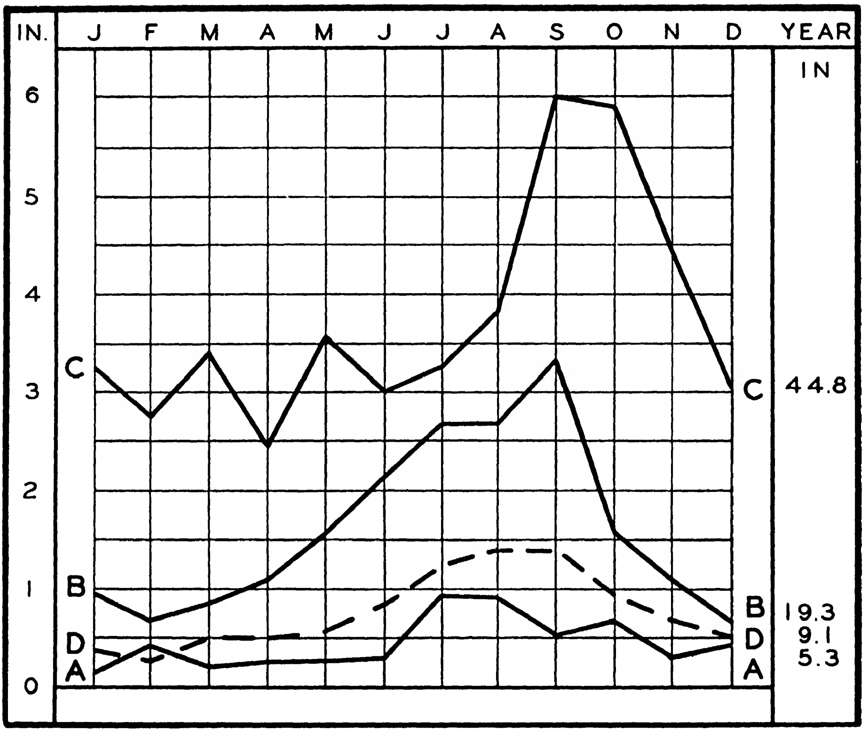

Fig. 65—Average Precipitation. Polar tundra of North America and Greenland.
A. Pt. Barrow, Alaska. C. Ivigtut, Greenland.
B. Hebron, Labrador. D. Jacobshavn, Greenland.

and the Arctic coast of Alaska (Fig. 65). There are cyclonic storms and precipitation at all seasons, but the precipitation is usually heaviest from July to September. This is the season when the polar cap of high pressure includes the northerly islands of Canada to latitudes 75°–80°, and when pressure is relatively low in the interior between latitudes 60° and 65°. Thus, because of the meeting of polar easterly and prevailing westerly winds, there are

frequent cyclones. In the colder months the precipitation is light because the wind movement is mostly outward from the center of the continent and because very little water vapor can exist under such cold conditions.

Most of the precipitation is snow which is largely in the form of minute spicules rather than flakes. These needle-like particles of snow pack solidly, especially when occurring with strong wind, and it requires only about two inches of such snow to make one inch of water. The Polar Eskimos use this densely packed snow in building their snow igloos. Because of the small amount of precipitation during the colder months, and because of its density, the snow does not accumulate to depths of more than one or two feet over most of the area, and where the winds are strong there is often much bare land even in winter. The ground is usually free of snow for three or four months.

Except for the two or three feet at the top that thaw during the summer, the ground is permanently frozen to great depths. The water thus released cannot penetrate into the subsoil, and makes much of the topsoil marshy and spongy; summer travel is thus difficult. Such soil does not warm much even under large insolation, for the sun's energy is mostly used in thawing and in evaporating the water. Thus, although the soil is sufficiently wet, both the soil and the air are too cold to permit any agriculture. Trapping, hunting, and fishing are the only means of support, except for some grazing of caribou and musk-ox in Canada and Greenland and of reindeer introduced from Siberia in the tundra of Alaska. The climate of the tundra does not prohibit settlement by its direct effect on man, but it very closely limits population by circumscribing the means of livelihood.

The Icecap Climate of Greenland (PI)

Greenland is an island continent lying between latitudes 60° N. and 83° N., much the greater portion being within the Arctic Circle. The narrow coastal fringe is very mountainous and has many deep and narrow valleys and fjords. As has been noted, this coastal belt has a tundra climate with marine modifications. Along the coasts south of latitude 73° N., two or three months of summer have mean temperatures above 40°, and the winters are moderate. The small valleys not only support sedges and mosses, but in favored situations grasses and some vegetables may be

grown. A short distance inland the land rises abruptly to 3,000 or 4,000 feet, and then slopes gently and smoothly upward to an elevation of 10,000 feet near the center. The entire interior is an enormous glacier plateau with a deep and continuous cover of snow and ice. It is estimated that the depth of the snow may be 6,000–7,000 feet at places in the interior. Over most of the surface the snow remains dry and crisp; near the borders there is some melting during the summer, and the surface covering becomes more ice than snow. This is the glacial ice cap from which innumerable glaciers move into the fjords and then, as icebergs, out to sea. The climate is well called *glacial*. It is a region without vegetation and without inhabitants. All that is known of the climate of this ice cap is the information obtained by occasional exploring expeditions.

The climate is a response to the latitude and altitude, the snow cover, and the pressure distribution over the adjacent waters. The snow cover reflects a large part, perhaps 80%, of the insolation it receives; the rest is used in evaporation or thawing, and there is little warming by conduction from below. Hence, there is little warming of the surface or the surface air even in the continuous insolation of mid-summer. On the other hand there is much loss of heat by outward radiation through the dust-free air. For these reasons there is at almost all times a marked surface inversion of temperature, a cold layer of air at the bottom which is 100 to 1,500 feet deep at times. This becomes particularly marked in the continuous night of the winter months. As a result, there are persistent katabatic winds, subject only to infrequent interruption, flowing downward under gravity from the central plateau to the borders of the inland ice and then into the valleys and fjords below. These winds form a shallow anticyclonic circulation, flowing out of the "glacial anticyclone" at the center of the ice cap. They are one of the marked characteristics of the climate.

In winter the Iceland Low is strongly developed, and many traveling cyclones move eastward from Canada a short distance south of Greenland. This increases the pressure gradient from the interior and intensifies the outward flow of the katabatic winds, and results in the inflow of warmer air masses aloft which bear considerable moisture. This is the cause of much cloudiness and the source of most of the precipitation on the ice cap. These turbulent conditions destroy the temperature inversion and bring

warmer air to the surface. Thus cloudy, snowy days are generally warmer than clear days, and occasionally there is rain up to heights of 6,000 feet. There is much stormy, cloudy weather on the ice cap, especially along the borders, and there is very little calm weather even at the center. Occasionally, blizzards with thick, whirling, blinding snow and temperatures of —40° or colder, make travel quite impossible.

So much of the snow falls at the same time that blowing snow picked up from the surface fills the air that it is impossible to measure the snowfall, and not much is known definitely about the amount of precipitation on the ice cap. A study of the snow layers marking the yearly accumulations indicates a fall of about twenty inches a year at the center, and more on the border of the ice cap. The principal loss of snow is by the descent and breaking off of the icebergs. There is little loss by evaporation or percolation. It is not known whether a balance is maintained, or whether the accumulation is increasing or decreasing.

Under the influence of the latitude, the elevation, the cold snow cover, and the surface inversion, the Greenland ice cap is certainly the coldest known area in the Northern Hemisphere in summer. The mean temperature of the warmest month is less than 32°, and in much of the higher portions it is probably less than 10°. The mid-winter temperatures probably at least equal those of eastern Siberia, and extreme low temperatures last for six months. The Wegener Expedition of 1930–31 maintained a station all winter at Mid-Ice (elevation 9,941 feet; latitude 70° 54′ N.; Longitude 40° 42′ W.) near the top of the ice cap.[1] Temperatures of —84° or —85° were recorded there in January, February, and March, and temperatures as low as —60° occurred on eighty-three days during the winter, the first on October 10 and the last on April 12. The mean temperature of the coldest month, February, was —60°, and that of the warmest month, July, was 7°. At the western base of this expedition on the border of the ice cap—elevation 3,100 feet—the temperatures were considerably higher; the lowest temperature recorded was —60°, the February average was —20°, and the July and August averages were 31°.

[1] F. Loew, "The Greenland Ice Cap as Seen by a Meteorologist," *Quarterly Journal, Royal Meteorological Society*, Vol. 62 (July, 1936), pp. 359–377.

CHAPTER XV

Climates of South America

The most significant fact about the continent of South Americ in relation to its climate is that much the greater part of it and a the broadest portion is within the tropics. Its widest region between 5° and 10° south of the equator. The only area outsic of the tropics is that part which narrows rapidly from a width about 1,600 miles at the Tropic of Capricorn to a point at Cap Horn at about 55° S. latitude. This farthest point south has latitude comparable to that of British Columbia, southern Labra dor, and the British Isles, in the Northern Hemisphere.

Another feature of climatic significance is the lofty and contin uous cordillera along the entire western border of the continen Through most of its length this mountain axis is an effective ba rier, separating a narrow coastal fringe on the west from the re of the continent, climatically as well as physically. Extensiv highlands in eastern Brazil, and in Guiana, northern Brazil, ar southern Venezuela, are also of climatic importance. These, to gether with the many plateaus in the Andes, give to South Ame ica a large area of tropical highlands.

General Characteristics

South America is essentially a warm-climate continent. It ha large areas of the three humid tropical climates and small areas the four subtropical types. There are small areas also of midd latitude steppe and desert and of humid marine climate. The are neither intermediate continental climates nor subpolar or pol types; in short, there are no cold climates.

Almost all of that part of the continent that is within the trop ics has an average sea-level temperature above 80°, but on th west coast the cooling influence of the Pacific Ocean carries th 70° isotherm northward to about latitude 5° S. In the prevailin westerlies, south of the subtropical highs, there are frequent cy clones and anticyclones resulting from the meeting of tropical ar

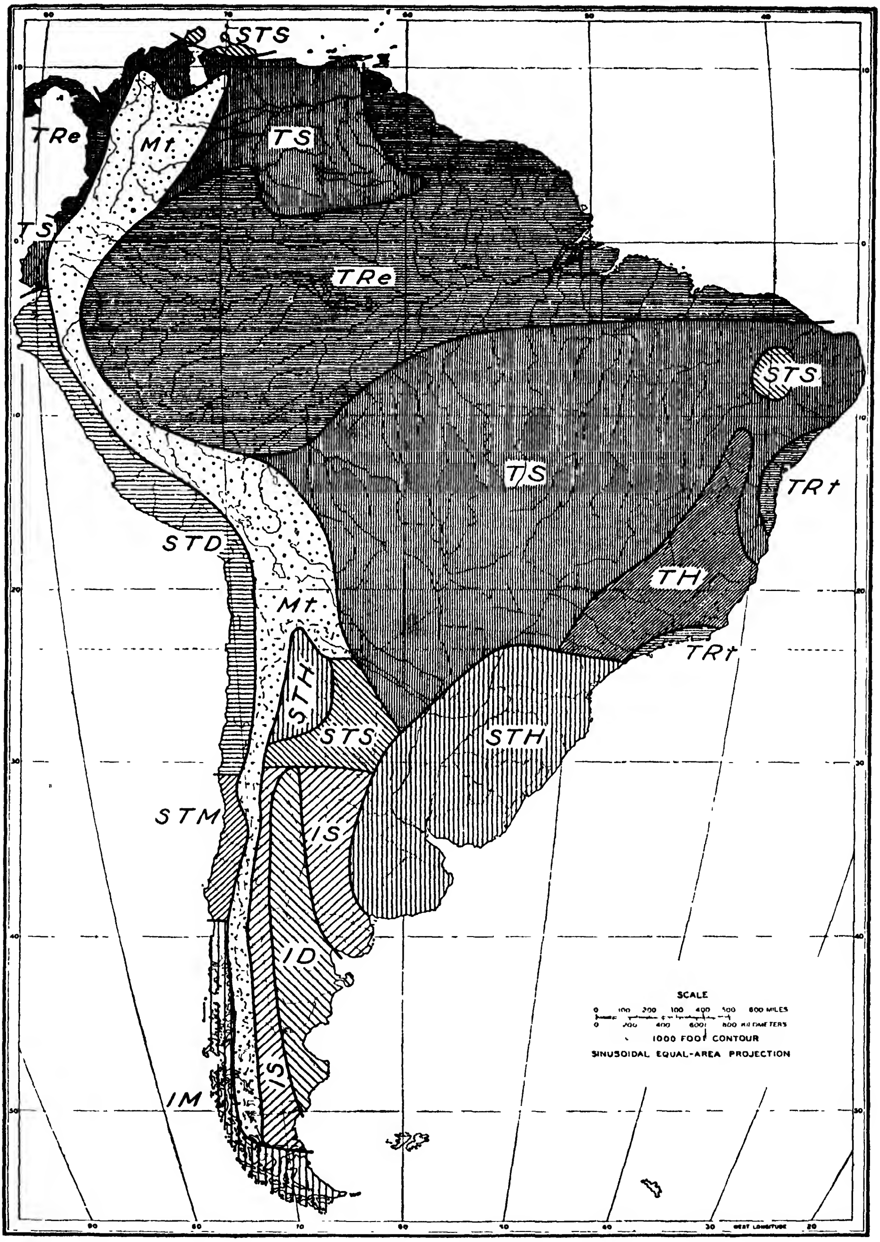

FIG. 66—Climates of South America.

TRe—Tropical Rainy (equatorial subtype).
TRt—Tropical Rainy (trade wind subtype).
TS—Tropical Savanna.
TH—Tropical Highland.
STS—Low Latitude Steppe.
STD—Low Latitude Desert.
STH—Humid Subtropical.
STM—Mediterranean.
IS—Middle Latitude Steppe.
ID—Middle Latitude Desert.
IM—Humid Marine.

(Base map by permission of the University of Chicago Press.)

polar air masses. The polar air masses are maritime and moderate in temperature, although decidedly cooler than the tropical air whether it comes from the interior of the continent or from the oceans. There are no polar continental air masses and no cold waves. Seasonal contrasts in temperature are small as compared with similar latitudes in North America; the winters are warmer and the summers are cooler. South America has no winters as cold as those of Iowa or Pennsylvania.

The equatorial belt of low pressure overlies the northern half of South America throughout the year. Its central doldrum area shifts from southern Brazil in January to northern Brazil and the northern border countries in July. Within this doldrum area, as it moves north and south of the equator, following the sun, heavy convectional showers occur, and into the area, as it migrates, flow the trade winds. The northeast trades are on the northern side of the doldrums; on the southern side the southeast trades extend to about 20° S. From about 20° S. to 40° S. the winds out of the south Atlantic high pressure center become northeast winds.

As a result of the movement of air from east to west in the doldrum and trade wind belts, there is an accumulation of warm ocean water in the western Atlantic in these latitudes, and therefore all these easterly winds are warm and moist winds. They lack the drying effect characteristic of trade winds in other situations. In the absence of high and continuous mountain systems on the north and east, these moisture-laden easterly winds penetrate the interior of the continent and become sources of rainfall throughout the interior as far as the eastern slopes of the Andes. Hence, nearly all of South America east of the Andes and north of 30° S. has an annual rainfall of more than forty inches. Between 30° and 40° S. latitude, where the winds parallel the coast or are offshore, the rainfall of the east coast is light and the interior is semiarid or arid.

On the west coast, the winds out of the South Pacific high-pressure center move nearly parallel with the coast, or trend offshore somewhat because of the deflection to the left resulting from the rotation of the earth. In addition, they pass over the relatively cold water of the Peru Current, which flows northward from 40° S. to the equator, and in places they also cross the still colder upwelling water alongshore. Hence, when the air does

move inland, its temperature increases and its relative humidity decreases. For these reasons the coastal plain between the equator and 40° S. is arid or semiarid. North of the equator, on the Pacific coast of Colombia, the winds turn inland around the interior center of low pressure, and produce heavy orographic rainfall on the western slope of the mountains. Over the whole area south of latitude 40° S., the influence of the prevailing westerlies is dominant, resulting in heavy rain on the west slopes and arid conditions on the east. The presence of the cold water of the Falkland current on the Atlantic coast adds to the aridity of southern Argentina.

The Tropical Rainy Climates of South America (TR)

An extensive area in South America has a continuously hot and moist climate, a tropical rainy climate of equatorial subtype (TRe). It is the largest area of its kind anywhere, and along the northeast coast of South America it includes an eastern strip of Venezuela, the northern half of British Guiana, all of Dutch and French Guiana, and northeastern Brazil almost to Cape San Roque. From the Brazilian coast it extends inland to include the vast Amazonian plain which spreads fanwise over western Brazil and into the borders of Colombia, Ecuador, Peru, and Bolivia. In addition, a small detached area of equatorial climate is found on the west coast of Colombia, and there are two small areas of the trade wind subtype (TRt) on the southeast coast of Brazil (see Fig. 66).

The Amazon plain

The plain of the Amazon has a length of about 2,000 miles from the Atlantic to the Andes. In its eastern portion it is about 200 miles wide, but in the west it broadens to more than 800 miles. It has a very gentle slope toward the Atlantic Ocean, and practically the entire plain is less than 500 feet above sea level, resulting in a vast area with an equatorial lowland climate (TRe). The rainfall is heavy throughout the area, amounting to about eighty inches a year on the coast and decreasing to about seventy inches some distance inland. Toward the west as the mountains are approached, the rainfall increases in places to 100 inches or more. The heaviest rainfall occurs from January to April, when the belt

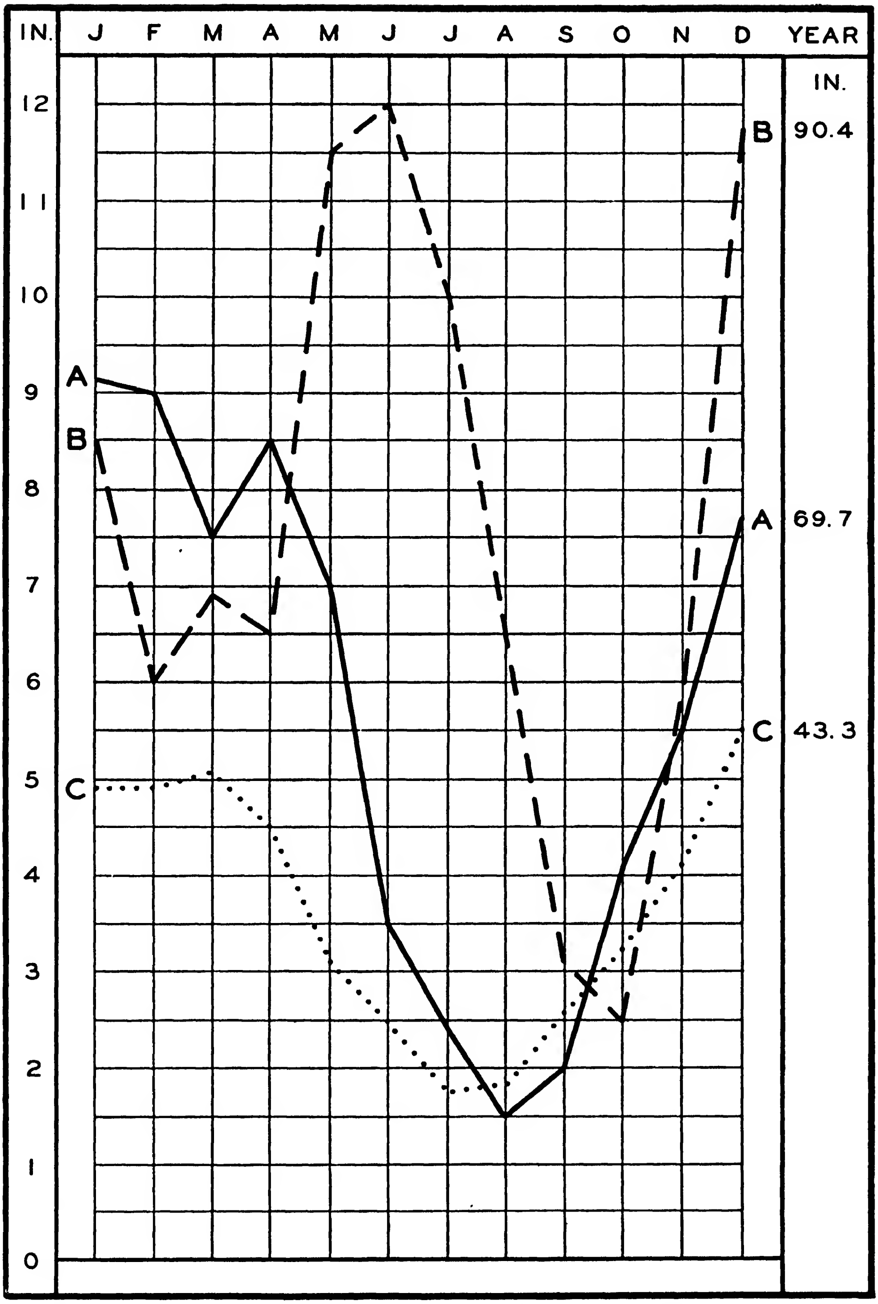

FIG. 67—Average Precipitation. Tropical rainy climates of South America. A. Monaos, Brazil (TRe). B. Georgetown, British Guiana (TRe). C. Rio de Janeiro, Brazil (TRt).

of lowest pressure is near or south of the equator and when the northeast trades are directed squarely onshore. There is generally a short, relatively dry season of two or three months, occurring between July and October, at the time when the doldrum trough is north of the area and when the trade winds do not blow directly inland. (Manaos, Fig. 67.)

The Amazon plain is a region of light winds and calms, or gentle trade winds. High winds are practically unknown, and no tropical cyclones invade the area. The rainfall is convectional, aided by orographic effects as the Andes are approached. It falls mostly as heavy showers of short duration during the afternoon or evening hours, and is sometimes attended by thunder and lightning. The morning hours are usually clear. The number of rainy days per year is between 150 and 200. The humidity is high throughout the year, averaging approximately 80%.

The temperatures are similar throughout the area, and are almost uniform throughout the year. The warmest weather generally occurs during the period of lighter rainfall and the coolest during the season of maximum rainfall. That is, cloudiness and rain have more effect on the temperature than do the slight seasonal changes in the elevation of the sun. The annual ranges are small throughout the area, not much greater in the interior than on the coast. Note in the accompanying table that Belém (Pará), at the mouth of the Amazon, has an annual mean of 78.6° with only 2.5° difference between the warmest and the coldest months, and that Manaos, 600 miles inland, but only 120 feet above sea level, is slightly warmer at all seasons, and has a range only 0.6° greater than at the coast. Iquitos and Cobija, 1,600 miles from the Atlantic, with elevations of 350 and 500 feet, respectively, average about 2° cooler than the coastal station, and have a difference between the warmest and coolest months of 4.3° to 6.5°.

The daily ranges of temperature are moderate, but greater than the annual ranges. Near the coast the daily maxima average 85°–87°, but the temperature seldom rises above 90°, and the daily minima average 72°–75°, seldom falling below 70°. Throughout the interior the daily ranges are somewhat greater, the days are somewhat warmer, the nights are cooler, and maximum temperatures above 95° and minimum temperatures of about 60° occur. The daily ranges average 15° to 20°. In the extreme west-

ern part of the plain, with a moderate increase in elevation, the minima fall below 60°, and the ranges rise above 20°. At Cobija, which is 11° of latitude south of the equator, the mean minimum is lowest in July—61.9°—and highest in February—70.7°. (Nevertheless June is the coolest month and September the warmest.) Temperatures have occasionally fallen as low as 50°, but mean maximum temperatures are above 81° in all months and mean daily temperatures above 72°.

With high average temperatures all year, and with high humidity, light winds, and heavy rain keeping the soil always moist, the climate is favorable for continuous growth of a dense vegetative cover, but is unfavorable for man. With sanitary precautions actual disease may be avoided, but the constant warmth and moisture are enervating and debilitating. An almost unbroken dense forest covers the Amazon plain, with large trees of many species interlaced with giant creepers. The forest canopy is so dense as to shut out the sun completely and to prevent the growth of grass or underbrush, leaving bare and damp ground. This is the typical rainforest or selva. In this area there is an immense supply of valuable lumber which has hardly been touched. The native products most exploited are rubber, Brazil nuts, and many kinds of palm nuts which are valuable for their oils. Clearing the forests for agricultural use, keeping the land clear, and maintaining fertility are difficult and expensive, and are not practicable for the individual farmer. The development of the country requires large organizations which are well-financed.

The Guianas

The Guianas have a hot, moist, and enervating climate with uniformly high temperatures and high humidity, and with heavy rainfall in all but two or three months. The mean annual range is only 2°–4°. The warmest months are September and October, which are also the months of least rainfall and most sunshine, and the average of these months is 81° to 84°. The coolest months are January and February, the normally coolest months of a marine climate in the Northern Hemisphere, and the means of these months are 77° to 82°, the higher means being some distance inland. The daily range, which is 10°–13° along the coast, rises to about 20° at interior stations 200–300 miles inland, owing to

higher maxima at these stations. On the coast the mean daily maxima are about 85°–87°, and temperatures seldom go above 90°. In the interior the daily maxima average above 90° every month of the year, and individual days with maxima above 100° are not uncommon.

TR *Climates of South America*	*Temperature*				*Precipitation*		
	Year	*Coolest Month*	*Warmest Month*	*Annual Range*	*Year*	*Wettest Month*	*Driest Month*
Amazon Plain							
Belém (Pará)	78 6	Feb. 77.4	Nov. 79 9	2.5	80.5	Apr. 17.8	Oct. 0.5
Manaos	81.0	Mar. 79 7	Sept. Oct. 82.8	3.1	69.7	Jan. 9 2	Aug. 1 4
Iquitos	76.6	July 74.1	Nov. 78 4	4.3	103.3	Mar. 12 2	Aug. 4 6
Cobija	76.4	June 72.4	Sept. 78.9	6.5	74.0	Mar. 15 0	July 0.5
Guianas							
Georgetown	80 0	Feb. 78.9	Sept. Oct. 81.2	2.3	90 4	June 11.9	Oct. 2 5
Paramaribo	79.5	Jan. Feb. 78.0	Sept. 81.7	3.7	90.4	May 12.2	Sept. 2.7
Cayenne	80.6	Jan. 79.2	Oct. 82.7	3.5	126.3	May 21.9	Sept. 1 2
Southeastern Brazil							
Rio de Janeiro	73.2	July 68 4	Feb. 78 7	10.3	43.4	Dec. 5.4	July 1 6
Colombia							
Andagoya	81.6	Nov. Dec. 81.0	Apr. 82.4	1.4	279.11	Apr. 26.01	Mar. 18 86

The rainfall of the area is mostly above eighty inches, and in many places it is above 100 inches annually. The wettest months are May and June, which is the time when the equatorial belt of low pressure is moving northward over the Guianas. A well-marked secondary maximum occurs in British Guiana in December, at the time when the pressure belt moves southward (Georgetown, Fig. 67). During these wet months the average rainfall is ten to twenty inches a month. The driest months are September and October, as in the greater part of the Amazon

Valley, and the amount during these months is generally less than three inches but more than one inch per month. In these drier and warmer months the mean relative humidity is about 70%; in the wetter part of the year it is about 80%. There are about 200 rainy days per year.

Pacific coast of Colombia

On the Pacific coast of Colombia the prevailing winds are directed inland throughout the year, toward the lower pressures of the interior. These winds are warm and moist, for instead of the cold Peru Current that prevails south of the equator, a warm equatorial counter current washes these shores. High mountain ranges parallel the coast and rise abruptly from a narrow coastal plain. For these reasons the coastal plain, the lowland valleys a short distance inland, and the western slopes of the mountains have extremely heavy rainfall. At Buenaventura on the coast at an elevation of thirty-nine feet the rainfall amounts to 280 inches a year, and the monthly amounts range from 11.34 inches in March to 34.66 in October. Andagoya, forty miles inland and 250 feet above sea level, has practically the same yearly rainfall and excessive amounts in all months (see table). These stations have about 300 rainy days a year. There are wide differences in rainfall at nearby stations, depending upon slope and exposure, and some stations have annual totals of fifty to seventy-five inches. On the whole, however, the Pacific coast of Colombia is one of the very wet regions of the world.

Tropical temperature conditions and high humidities also prevail in this area. Note the extremely small annual range of only 1.4° at Andagoya. Each month has a mean temperature of either 81° or 82°. The monthly mean maximum temperatures range from 88.0° to 89.8°, and the monthly mean minimum temperatures range from 73.5° to 75.0°, giving a very uniform difference of about 15° between daily maxima and minima. Every day throughout the year the temperature rises to 88° or 90°, and every night it falls to 74° or 75°. This statement gives a correct general picture of the climate, although there are occasional exceptions; the extremes of record are 100° for a maximum and 66° for a minimum. This area is, therefore, an excellent example of the equatorial, tropical rainy climate; it is wet, enervating, and oppressive

—a swampy region of tangled mixed forests and creeping vines. Palms abound in a great variety of species.

Southeast coast of Brazil

On the southeast coast of Brazil there are two small areas of tropical rainy climate of the trade wind subtype (TRt). These are narrow coastal plains terminated inland by an abrupt rise to upland or highland areas. The rising land causes an upward movement of the inflowing trades and facilitates convection under quiet conditions. Hence these coastal plains and seaward slopes have more rain than the adjacent savannas and highlands. The northern area, approximately between latitudes 11° S. and 17° S., has a rather even distribution of precipitation, but January is usually the wettest month. The southern area, represented by Rio de Janeiro, (Fig. 67), has a distinct maximum in summer, November to March, and a minimum in July and August. The summer maximum is the consequence of decreased wind movement and increased convectional activity associated with the southward movement of the equatorial belt of low pressure. During the summer half year, the heat and humidity are depressing and enervating. In the Rio de Janeiro area, near the Tropic, there is an annual range of 10° in temperature, and the cooler months, May to October, are pleasant. The rainfall over most of these areas is sufficient to maintain a constantly moist soil, and the slopes of the hills are covered with a dense tropical rainforest.

The Tropical Savanna Climate of South America (TS)

During the winter of the Southern Hemisphere, the equatorial belt of low pressure moves north of the equator, and pressure increases over the continent south of the equator. At this season there is some settling of air and some movement outward from interior Brazil. Hence the low-sun season is a dry season over much of tropical South America below the equator. The area having a tropical savanna (TS) type of climate, with tropical temperature conditions but with a distinct dry season, includes a large part of central and eastern Brazil between latitude 5° S. and the Tropic, omitting the truly highland and mountainous region in eastern Brazil. It includes also as a contiguous area that part of

Bolivia east of the highlands and the disputed Chaco region between Bolivia and Paraguay.

A small area on the coast of Ecuador, just south of the equator, forms a transition zone between the tropical rainy climate of the Colombian coast and the dry climates of Peru, and has a savanna climate. In the Northern Hemisphere most of Venezuela, the eastern portion of Colombia, and a small area in northern Colombia have a similar type of climate. This region has a dry season in winter at the time that the northeast trades are well-developed. These trades carry relatively cool air from the North Atlantic over the warm lowlands of Venezuela, and they are, consequently, dry winds.

Although the savannas of South America have an annual rainfall of more than forty inches over most of this area, the existence of a dry season of several months' duration prevents the development of forests, and the regions are typically grassy plains with occasional patches of shrubs and stunted trees; on the wetter side these regions merge into forested areas and on the drier side they merge into semiarid plains. *Savanna* is the general name for such grasslands; in Brazil the local name is *campos*, and in the Orinoco valley of Colombia and Venezuela they are known as *llanos*.

Interior Brazil and eastern Bolivia

The great grasslands of interior, upland Brazil and eastern Bolivia are thinly populated in spite of large resources and a climate less oppressive than the steaming lowlands of the Amazon plain (see table). Mean annual temperatures, mostly between 72° and 80°, are not much different from those of the tropical rainy province, but there is somewhat more seasonal contrast, as is evinced by an annual range of 5° to 12°. In the southwest portion near the Tropic of Capricorn, maximum temperatures of 110° have occurred, but on the other hand the mean temperature of the coldest month approaches 65°, and freezing temperatures occur occasionally. (The climate is therefore not strictly tropical.)

The annual rainfall is from forty-five to seventy inches, with a distinct maximum in the high-sun period, December to February; the wettest month at most places is January. A well-marked dry period occurs in the cooler part of the year, beginning in May or June and lasting until August or September. There are three

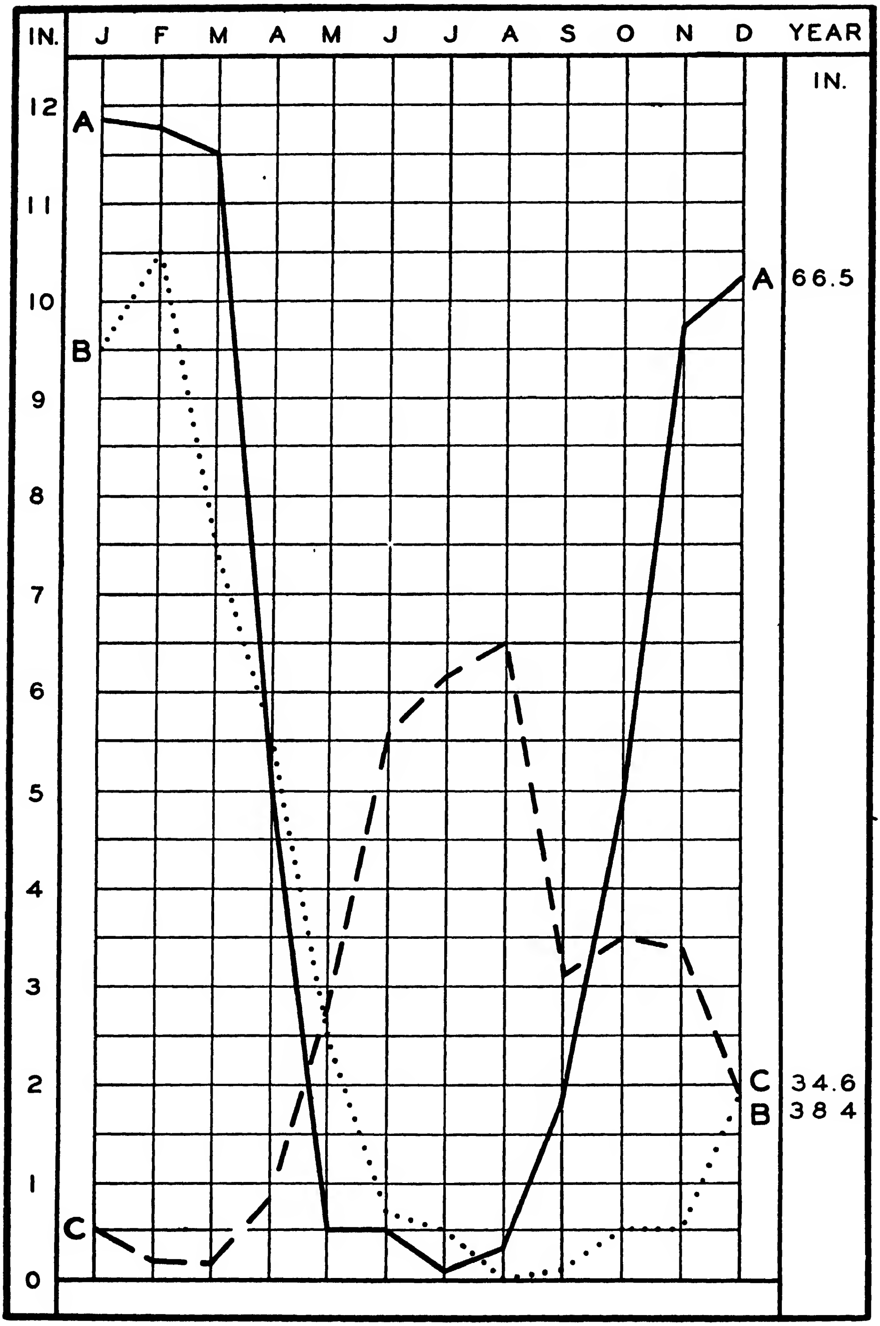

FIG. 68—Average Precipitation. Tropical savannas of South America.
A. Goyaz, Brazil. B. Guayaquil, Ecuador. C. Ciudad Bolivar, Venezuela.

to five months with less than two inches each, and one or two months are almost rainless. July is usually the driest month, averaging from 0.10 to 0.30 inch (Goyaz, Fig. 68). In the extreme eastern angle of Brazil there is a coastal region with a tropical savanna type of climate in which the maximum rainfall occurs between April and July, as the doldrums migrate northward, and in which the minimum occurs in October to December, when the doldrums have moved south and when the trade winds parallel the coast. During these three dry months the rainfall is about one inch per month or less, but monthly amounts range from eight to twelve inches during the rainy season. This coastal region is hot and humid and approaches the tropical rainy type of climate. It produces cotton and cane sugar extensively.

In the main portion of the Brazilian savanna, natural forage is the chief resource. Great expanses of nutritious grasses support millions of cattle. There are some areas where the grasses are coarse and wither during the dry season. Cassava, rice, beans, and tropical fruits are grown in places. Eastern Bolivia has, in addition to grassy plains, areas of swamp, jungle, and forest resulting from heavy rains and poor drainage. The forests are of rubber and hardwoods.

Coastal Ecuador

The coastal plain of Ecuador rises abruptly about 200 feet above the shore line and then extends inland fifty to 100 miles. It has well-defined wet and dry seasons. The wet season is the warm season and the dry season is cool, contrary to the usual regime in regions so near the equator. In the northern winter, warm equatorial ocean waters extend southward to the Ecuadorean coast, and onshore winds from over the warm water result in high temperatures and heavy rain, as on the Colombian coast. January and February are especially wet. In the southern winter the cold Peruvian (Humboldt) current extends north as far as Ecuador, displacing the warm water and resulting in lower temperatures and only light rainfall from June to November. This cool water does not reach as far north as Colombia, and for this reason the coast of Ecuador has several months of cooler weather than that which occurs on the Colombia coast. Cacao is grown in the allu-

TS *Climates of South America*	*Elevation (Feet)*	*Temperature, °F.*				*Precipitation (Inches)*			*No. Months Rainfall Less than 2 inches*
		Year	*Coolest Month*	*Warmest Month*	*Annual Range*	*Year*	*Wettest Month*	*Driest Month*	
Brazilian upland									
Goyaz	1906	75.2	Je, Jl 72 3	Sept. 78.1	5.8	66.5	Jan. 11.9	July 0.1	May–Sept. 5
Cuyaba	541	79 7	July 74.8	Oct. 82.6	7.8	54.7	Jan. 9 6	July 0 2	June–Aug. 3
Corumba	381	76.6	June 69.4	Jan. 80 2	10.8	49.1	Dec. 7.4	July 0.3	June–Aug. 3
Brazilian Coast									
Recife	98	80.2	July 77.0	March 82 2	5.2	65.1	June 11.2	Oct. 1.0	Oct.–Dec. 3
Paraguay									
Mission Inglesa	361	75.1	June 66.4	Jan. 83.2	16.8	46.8	Jan. 6 1	Aug. 0.8	Aug. 1
Ecuador									
Guayaquil	39	78 3	July 75.4	Apr. 80 4	5.0	38.4	Feb. 10.5	Aug. 0.0	June–Dec. 7
Venezuela									
Ciudad Bolivar	125	81.5	Jan. 79.2	Sept. 83.2	4.0	35.2	Aug. 7.0	Feb. 0.2	Dec.–Apr. 5
Calabozo	328	81.4	July 78.7	March 84.2	5.5	47.2	July 9.0	Feb. 0.0	Dec.–Mar. 4
Caracas	3419	78.5	Jan. 65.8	May 70.8	5.0	32.2	Aug. 4.3	Feb. 0.4	Dec.–Apr. 5

vial lowlands of Ecuador, and coffee is grown on the slopes. Some sugar cane is also cultivated.

Venezuela and eastern Colombia

Venezuela and adjacent portions of southern British Guiana, northern Brazil, and eastern and northern Colombia have a tropical savanna climate of the Northern Hemisphere, similar to that of the northern portion of the Brazilian savanna with the seasons reversed. Because the region lies only 1° to 12° north of the equator, seasonal differences of temperature are unimportant; the months of maximum and minimum temperature are determined by relative amounts of cloudiness and rainfall or by local exposure and elevation.

The typical savanna area is the lower portion of the Orinoco Basin, comprising a large part of central Venezuela and extending into northeastern Colombia. These are the *llanos*—hot, moist, grassy plains with a mean annual temperature of 81° to 84° and with only 4° to 6° difference between the warmest and the coolest months. Maximum temperatures above 90° occur in all months, and the lowest temperatures ever experienced are above 65°. The daily range of temperature is 10° to 16°. The rainfall shows considerable local variation, and ranges from twenty-five to fifty inches a year (Ciudad Bolivar, Fig. 68). It is light from January to April under the influence of the steady, dry northeast trade winds, increases rather rapidly to a maximum in June, July, and August while the area is in the belt of low pressure and quiet air and while convection is active, and then decreases slowly until the end of the year. The coastal plain around Lake Maracaibo and the northwest coastal region of Colombia have a similar climate, except that the wettest months are September, October, and November, and that in the vicinity of Lake Maracaibo the annual total is less than twenty-five inches. Along the immediate coast of Venezuela west of Caracas and in the northern tip of Colombia, the rainfall is generally less than twenty inches and the climate is of the low latitude steppe type.

The tropical savanna of northern South America comprises, then, the Orinoco llanos, the Maracaibo Basin, and the coastal plains of Venezuela and northern Colombia, and it has an elevation ranging from sea level to 2,400 feet. It is a *tierra caliente*

(warm land) and produces sugar, cacao, coconuts, cotton, tobacco, bananas, and corn. The Maracaibo Basin is separated from the Orinoco Valley by a northeast spur of the Andes, the Cordillera de Merida, which has a considerable area between 2,400 and 6,000 feet. This is a *tierra templada,* or temperate land, with a tropical highland type of climate (see Merida in following table). But Caracas, near the coast at an elevation of 3,400 feet, has a tropical savanna climate with all months averaging above 65°, although it has a record minimum of 45°. Coffee is the principal crop of the area between 1,500 and 6,500 feet. This highland region above 1,500 feet, with its more moderate temperatures, is the most highly developed and the most thickly populated agricultural region of Venezuela and Colombia.

In southern Venezuela and adjacent portions of Brazil and British Guiana are the Guiana Highlands, a hilly or mountainous area of moderate elevation which is thinly populated and without climatic records. But it appears that the region has a tropical savanna climate with increased rainfall over that of the lower Orinoco Valley and a shorter dry season. There are some areas of open grassy *campos,* but in places the grasslands give way to forested hills.

The Tropical Highlands of South America (TH)

Near the southeast coast of Brazil from latitude 8° S. to 30° S., a considerable area rises to elevations between 2,000 and 5,000 feet. This is geologically the oldest portion of the continent, and consists of plateaus and rounded hills with a steep escarpement on the seaward side. In places this escarpement approaches almost to the shore, leaving only a very narrow coastal plain, back of which there is a sudden rise of 2,000 feet or more. From Santos to Sao Paulo, a distance of fifty miles, there is a rise of 2,500 feet. The Brazilian Highland between 12° S. and the Tropic of Capricorn has a tropical highland type of climate (TH), such as has been described for the highlands of Central America and Mexico.

The Andes system, running the entire length of the continent near its western boundary, consists of an almost unbroken chain within twenty to 100 miles of the coast, and in its northern half also of one or more parallel ranges farther east. This Andean cordillera is a young mountain system with an average height of

TH *Climates of South America*	*Elevation (Feet)*	*Temperature, °F.*						*Precipitation (Inches)*			*Mean Relative Humidity, %*
		Year	*Coolest Month*	*Warmest Month*	*Annual Range*	*Daily Range*	*Extremes*	*Year*	*Wettest Month*	*Driest Month*	
Sao Paulo, Brazil	2690	63.7	July 57 9	Feb. 69.1	11 2	. .	. .	56.2	Feb. 8.7	July 1.7	. .
Bello Horizonte, Brazil	2812	68.2	July 62 2	Feb. 72.1	9.9	. .	.	59.1	Jan. 12.8	July 0.4	. .
Merida, Venezuela	5384	67.0	Jan. 64 8	May 68.2	3.4	16 0	85 52	71.8	May 11.0	Feb. 1.6	79
Bogota, Colombia	8678	57.1	July 56.1	March 58.2	2 1	13 4	74 40	41.8	Oct. 6.3	July 2.0	72
Quito, Ecuador	9350	57.2	July 56 6	Oct. 58.0	1.4	23.5	79 35	43.1	Apr. 7.2	July 0.8	72
Arequipa, Peru	8040	57.8	July 57.2	Dec. 58.3	1.1	20.3	82 36	4.2	Feb. 1.7	Sept. 0.0	54
Sucre, Bolivia	9344	54.0	July 49.3	Dec. 57.4	8.1	19.7	82 25	26.2	Jan. 6.3	June 0.1	60

13,000 feet and a number of peaks rising above 20,000 feet. Within this vast mountain system there are many plateaus and high intermountain valleys, many of which are 10,000 to 14,000 feet above sea level. In these mountains and on their borders there are many climatic types arranged in zones according to elevation. The types range from tropical lowland climates at the foot of the mountains to subtropical and intermediate types, and to polar climates on the barren, rugged upper reaches of the mountains. In the highest portions there are glaciers in sheltered valleys even at the equator. These climatic and vegetative zones are distinctly marked, and correspond closely to the elevation contours. The most populous areas and those of greatest agricultural importance are those plateaus and valleys between 4,000 and 10,000 feet in elevation, found from Venezuela and Colombia southward to extreme northern Argentina. These have the typical climate of highland areas within the tropics. They are tropical in their small annual ranges of temperature, but subtropical to intermediate in their mean temperatures.

Brazilian highland

This tropical highland region of moderate elevation has a mean annual temperature of 63° to 68°, which is about 10° lower than that of the adjacent lowlands, and about the same as the annual mean in the Gulf States of the United States. The annual range, however, is only 10° to 12°, as compared with 30° to 35° in our Gulf Region. The coolest month is the midwinter month of July, when the mean is 58° to 62°—about the same as March or April in the Gulf States. The warmest month is February—a retardation of about a month after the summer solstice, as is frequent in highland climates. The February mean is 69° to 72°, comparable to the temperature of May in the Gulf States. The climate is therefore very equable and pleasant, although temperatures above 95° occur occasionally in summer, and frosts are not unknown in the higher portions in winter.

Precipitation ranges from forty to eighty inches, mostly from fifty to sixty inches, and much the larger part of it occurs in the summer half-year, October to March. The wettest months are the three midsummer months, December, January, and February, while the center of low pressure is over interior Brazil (Sao Paulo,

Fig. 69). There is a distinct dry season during the winter half-year, with July the driest month, under the influence of the subtropical belt of high pressure. This distribution of temperature and precipitation (a warm wet season and a cool but not frosty dry season) is highly favorable to the production of coffee, and about two-thirds of the world's supply is produced in this small portion of Brazil. The climate is also favorable to the production of cotton, sugar cane, tobacco, and subtropical fruits.

Tropical highlands of the Andes

Many of the valleys of the Andes, from Venezuela to Bolivia, inclusive, have moderate mean annual temperatures which are largely governed by elevation; the range is from about 54° to 67°, with the temperature of the warmest month about 57° to 68°, and the coolest month 50° to 65°. The highlands are thus truly tropical in the uniformity of the monthly means. Daily temperature ranges average about 14° to 24°, most of the higher plateau stations, especially, showing a rapid cooling by night, when the surface air becomes stable. There is only a moderate warming by day, in spite of thin dry air and a nearly vertical sun, because the heating of the surface air results in convective movements and the inflow of cooler air from greater heights. In the map of climatic provinces, Fig. 66, the tropical highland valleys are not differentiated from the mountain climates by which they are surrounded.

Although the highest temperature of record at Merida, Venezuela, is 85° (see table), temperatures of 80° or above have occurred in all months except December and January. The lowest recorded temperature is 52°, but temperatures as low as 56° have occurred in all months. Even at Quito on the equator, temperatures have never risen as high as 80°, but they have fallen at night to 35°. At Sucre, Bolivia, over 9,300 feet above the sea and nearly 20° south of the equator, temperatures are not truly tropical, and freezing temperatures are common at night in the winter months.

The temperatures mentioned in these highland areas are typical spring temperatures of middle latitudes, but the effect is not the same; there are certain modifications in effect, due to the elevation of these areas and their situation in the tropics. The latter accounts for the slight variability of daily and monthly means.

The elevation results in certain heating and cooling effects not felt in lowlands (see *Altitude as a climatic control* in Chapter V). At these elevations the air is thin, and the total amount of dust and water vapor above the surfaces is small. Hence there is little ab-

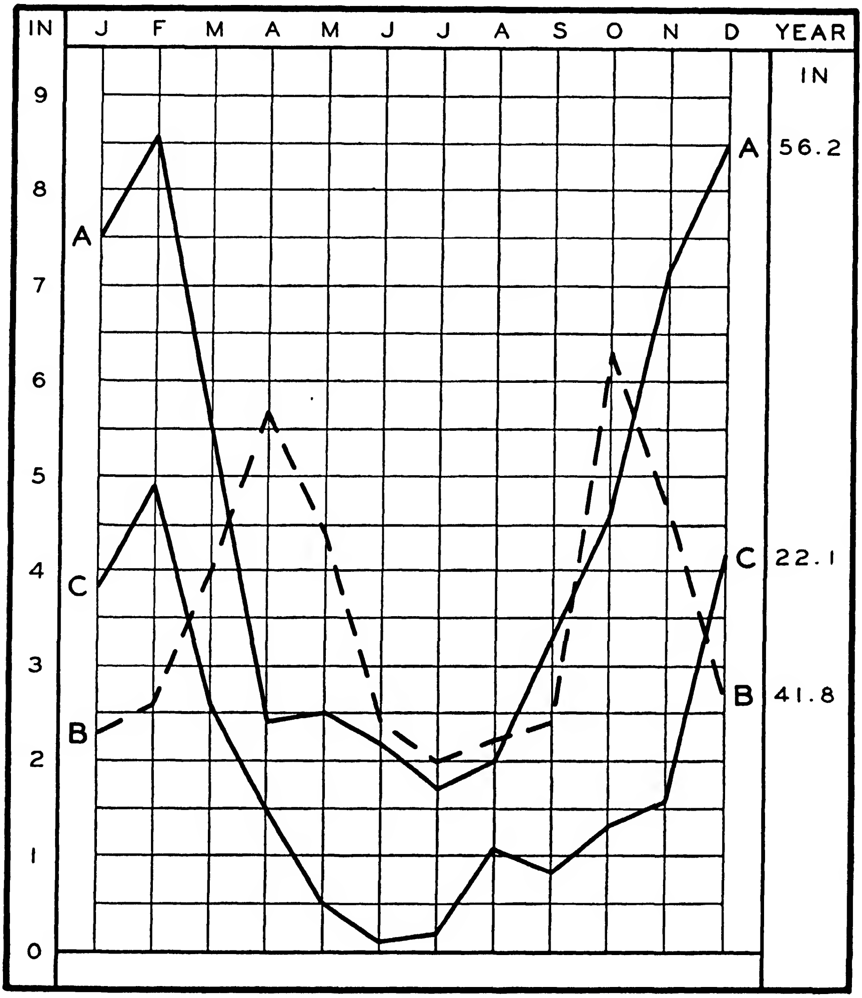

FIG. 69—Average Precipitation. Tropical highlands of South America.
A. Sao Paulo, Brazil. B. Bogota, Colombia. C. La Paz, Bolivia.

sorption either of incoming or of outgoing radiation. This means that solar radiation is intense, and that soil, plants, and persons are warmed rapidly in the sunshine, although the air itself remains cool or moderately warm. In the sun the weather seems much warmer than it is, and by contrast one is often too cool in the

shade. At night for the same reasons there is rapid radiation of heat from soil and plant surfaces, the air feels raw and cold, and frosts are common whenever the air temperature falls to 40° or lower.

The highland valleys of Venezuela, Colombia, and Ecuador are well-watered, having an annual precipitation of forty to seventy inches. There are two distinct wet periods, April–May and October–November, which are caused by the migration of the pressure belts and wind systems (Bogota, Fig. 69). At Merida there is only one month, the month of February, with less than two inches of rain. In Colombia and Ecuador there is a dry season of three months' duration; June, July, and August each have about two inches of rain or less. In Peru the highland valleys, like the lowlands, are dry, and Arequipa, which has a mean annual rainfall of only 4.16 inches, is permanently arid. The Bolivian highlands receive a somewhat better supply of moisture, annual amounts ranging from fifteen to thirty inches. Most of the rain in the Bolivian highlands falls during the summer half-year, October to March, and the winter months receive less than one inch each. This is the Southern Hemisphere regime as found in tropical Brazil.

Throughout these highlands the rainfall is largely convectional, falling as afternoon thunderstorms. A typical day during the rainy season begins bright and clear. By noon clouds are gathering, and in the afternoon there is a violent thunderstorm, often attended by hail and snow, for the free air at these heights is cold. The snow quickly melts on the warm soil, and toward evening the clouds disappear. The night and early mornings are again clear and cool.

Agricultural relations

In the Venezuelan highlands the climate is very similar to that of the Brazilian highlands, and is also especially adapted to coffee growing. Accordingly, coffee is the major crop of Venezuela. Coffee-growing is also the principal industry of the upland valleys of Colombia, but in Ecuador coffee is second to cacao. The greater part of the central plateau of Peru is above 9,000 feet, and is too dry and chilly for much agriculture. It is largely uninhabited waste land. The eastern slopes and intermediate valleys, leading

down to the Amazon valley, are better watered, and although the drop to the tropical lowlands is very rapid, there are some level fertile areas with a subtropical climate. Some of these areas are forested and some are grass lands, now devoted to crops, including coffee. In Bolivia the Andean system reaches its greatest width, and two-fifths of the nation consists of mountains or high tableland. The large central plateau region of Bolivia, like that of Peru, is mostly too high and dry for much agricultural use. Its temperatures are intermediate, and the principal crops are the cold climate crops, barley and potatoes. On its eastern side the plateau slopes gradually downward to the Brazilian upland savanna, and the best agricultural area of Bolivia is in the subtropical zone of these slopes at elevations of 4,000 to 8,000 feet. In all of these areas of intermediate height, from Colombia to Bolivia, the typical warm climate crops, cotton, sugar cane, and tobacco—in addition to coffee—are also grown extensively. On the highlands and slopes of northwestern Argentina, sugar cane, mainly under irrigation, is the most important crop. Throughout the tropical Andes there are higher, cold valleys in which the common grains and vegetables of middle latitudes are the principal crops. (Compare the Andean highlands with those of Central America and Mexico as to elevation, temperature, rainfall, and agricultural use.)

The Humid Subtropical Climate of South America (STH)

The major portion of South America is tropical, as has been noted. All the remainder, which is that portion south of the Tropic of Capricorn, has a moderate climate, either subtropical or mild intermediate. There are some steppe and desert regions and a small area having a Mediterranean type of climate, but the largest and most important region has a humid subtropical climate (STH).

This type of climate is found on the eastern sides of all the continents, beginning near the Tropics of Cancer or Capricorn and extending about 15° of latitude poleward. In South America it extends from the Tropic, where it crosses Brazil and Paraguay, southward to about latitude 38° S. on the coast of Argentina. It reaches westward to the Paraná River and as far as longitude 65° W. in central Argentina. All of Uruguay is thus included. This is a compact area which is somewhat larger than the similar cli-

matic region in the southeastern United States, and which extends into higher latitudes because it is less subject to continental influences. It has no cold waves because there are no large continental land masses in higher latitudes.

The general climatic characteristics of the area are (1) warm summers and mild winters, and (2) adequate rainfall fairly well

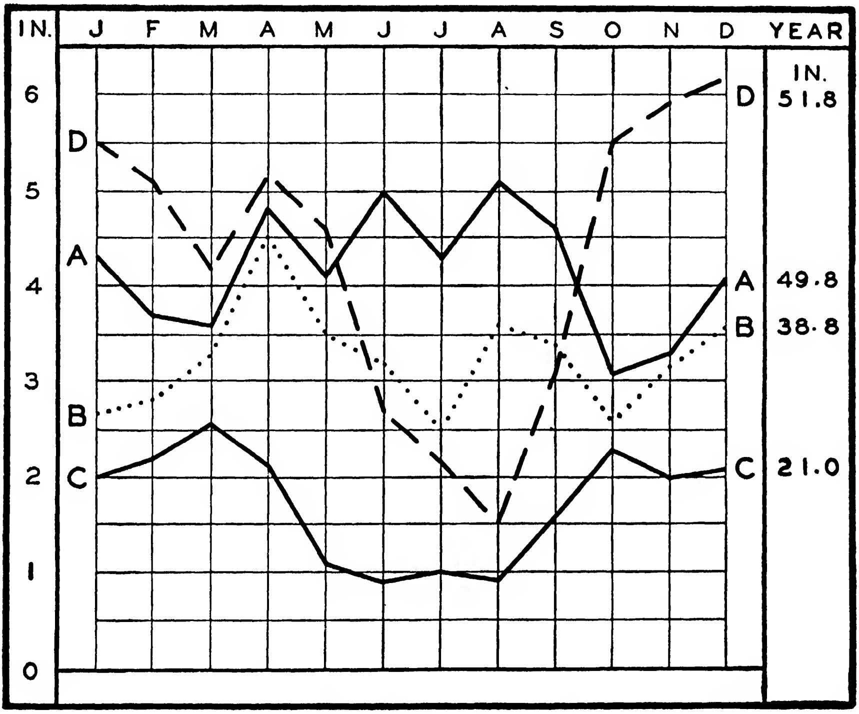

FIG. 70—Average Precipitation. Humid subtropical climate of South America.
A. Porto Alegre, Brazil. C. Bahia Blanca, Argentina
B. Montevideo, Uruguay. D. Asuncion, Paraguay.

distributed throughout the year. The climate is more equable than in the humid subtropical region of the United States; that is, the summers are cooler and the winters are somewhat warmer. The annual mean is slightly lower. There are occasional hot days in summer with maxima well over 100°, and there are, except along the northern border, occasional winter minima below freezing; there are, however, no severe freezes such as occur at intervals with the cold waves in the southeastern United States. Throughout the area the mean temperature of the coldest month is below 65° but above 43°. The rainfall over most of the region

is between thirty-five and fifty-five inches. The amount is generally greater in the summer half-year, but there is considerable variation in the time of occurrence of the maximum (Fig. 70). Much of the precipitation is convectional, and the number of thunderstorms ranges from thirty to sixty a year. During the winter months there are cyclonic storms.

South Brazil

That portion of Brazil between the Tropic and latitude 30° S. consists of a narrow coastal plain, and, behind it, an upland plain averaging about 2,000 feet in elevation; that part south of latitude 30° S. is a lowland plain. Temperatures in southern Brazil average 5° to 10° lower than in Rio de Janeiro, the difference being largely in the winter months. The annual range is 20° to 24° instead of the 10° at Rio de Janeiro. The mean winter temperature at Porto Alegre is somewhat higher than at Los Angeles and New Orleans; the summer temperature is 5° warmer than at Los Angeles and 6° cooler than at New Orleans. The temperature regime is similar to that of the tropical highlands into which the area merges on the northeast, but the summers are warmer and the winters are cooler. The temperature of the coolest month is about 55°. Frosts are not uncommon, especially in the southern half, and snow is not unknown in the higher areas.

The rainfall is fifty to sixty inches a year and quite evenly distributed, without definite seasons of maximum or minimum. The native vegetation is dense tropical forest or more open pine forest in the north, merging into grasslands in the south. The area is largely devoted to forest industries and to grazing of cattle and sheep. *Yerba maté,* or Paraguayan tea, is produced in large quantity. This bush is native over most of the subtropical area. The region is too frosty for coffee; the typical subtropical crops for which the climate seems suitable have not been developed.

Paraguay

Paraguay, between the Paraná and the Paraguay rivers, is a country of hills, valleys, and upland plains, but the general level is mostly under 1,000 feet. It is an interior country of hot summers and mild winters, averaging only slightly under the tropical limit of 65°. But the daily range is high—over 20°—and occasional

freezing temperatures occur on winter nights. The summers are hot and maximum temperatures above 100° have been recorded in all months from October to March. Wind directions are variable. Northerly winds bring hot, moist, and enervating air from the interior of tropical Brazil; the southerly winds are relatively dry, cool, and invigorating; but on the whole the climate is not very stimulating, and the people are not very energetic. The summers are like those of New Orleans, with three months above 80°; the winters are like those of Tampa, averaging between 60° and 65°. Precipitation ranges from fifty to seventy inches, with a distinct maximum in summer and minimum in winter, but without a pronounced dry season such as occurs in the Brazilian *campos* to the north.

The higher eastern areas are forested, but the greater part of the country is open grassland similar to the adjacent plains of Argentina. The production of *yerba maté,* which grows wild, is the principal industry, and cattle raising is second, but cotton, coffee, tobacco, sugar cane, pineapples, and oranges grow readily. Oranges grow abundantly even when neglected and uncultivated.

Uruguay

This is a compact small country with a narrow coastal plain back of which is an undulating or hilly upland less than 1,000 feet in elevation. It has distinct winter and summer seasons, for it lies between latitudes 30° S. and 35° S. and is comparable in position to the area between northern Florida and the southern boundary of Virginia. Because of preponderately easterly winds, it is subject to much marine influence, and average temperatures are moderate at all seasons, as are also the seasonal differences (22° to 24°). Maximum temperatures above 100° occur occasionally in summer in air moving from the heated northern interior, and at rare intervals winter temperatures fall to 22° or 25° on good radiation nights of clear quiet air. Winter temperatures never fall to 0° or 10° as happens on infrequent occasions in our Gulf and South Atlantic states.

Rainfall for the most part averages thirty-eight to forty-six inches, but a few places in the north have more than fifty inches a year. Distribution is fairly uniform; all months have more than two inches, and, in most parts, more than three inches. In general

the wettest months are March and April. Uruguay has a mild, pleasant, healthy climate of moderate stimulus. The native grasses of the upland plains support vast herds of cattle and sheep, and livestock raising is the principal industry. The cultivation of wine grapes and olives, and the presence of palms, acacias, and eucalyptus trees attest the subtropical character of the climate. The plains are "gay with the scarlet verbena and other brilliant wild flowers" and the upland valleys are "fragrant with aromatic shrubs."

Humid subtropical Argentina

The remainder of the humid subtropical region of South America comprises that portion of northeastern Argentina adjacent to Paraguay, Brazil, and Uruguay westward to the Paraná River, and that portion of eastern Argentina between the Plata River and Blanca Bay (latitude 38° S.), extending westward to longitude 65° W. There is also a small detached region of humid subtropical climate in extreme northwestern Argentina (provinces of Tucuman, Salta, and Jujuy) in which the summers are wet and the winters decidedly dry—a fertile and attractive region in which sugar cane is the most important product.

In the vicinity of the Plata estuary cnmatic conditions are much the same on the Argentine side as in Uruguay. (Compare Buenos Aires and Montevideo.) The mean temperatures of June and July are slightly below 50°, but freezing temperatures are rare. Tropical plants such as the palm flourish, and the growing season is practically continuous. The rainfall is about thirty-seven inches a year, with a maximum in early autumn, March and April, when the pressure in the interior of the continent is relatively low; there is a minimum in winter, June to August, when the subtropical ridge of high pressure crosses the continent in these latitudes.

Northeast Argentina in the valley of the Pananá River is an inland region bordering Uruguay and southern Brazil on the west. It is a flat, poorly drained, humid area in its eastern portion, becoming higher and drier west of the river and making a gradual transition into a steppe climate. At Corrientes on the Paraná River the mean temperatures of all months are above 60°, the mean maximum is above 90° for three months, and temperatures

STH *Climate of South America*	Elevation (Feet)	Temperature °F. Mean Annual	Coolest Month	Warmest Month	Annual Range	Mean Daily Range	Abs. Max. & Min.	Precipitation (Inches) Annual	Wettest Month	Driest Month	Mean Cloudiness	Mean Rel. Hum., %	No. Days Freezing Temperature
Brazil													
Porto Alegre	49	66 9	June 56 3	Feb. 76 5	20 2	. . .		49 8	Aug. 5.1	Oct. 3 1	. .	. .	. .
Uruguayana	249	66 9	June 54 9	Jan. 78 8	23 9	. . .	. .	51 4	March 6 9	July 2 8	. . .	. .	. .
Paraguay													
Asuncion	300	72 3	June 62 6	Jan. 80 4	17.8	20.5	109 33	51.8	Dec. 6 2	Aug. 1 5	4 9	71	. .
Puerto Bertoni	515	70.8	July 60 8	Jan. 79 4	18.6	24.6	108 28	70 1	Nov. 7 6	July 3 4	. . .	. .	. .
Uruguay													
Montevideo	26	61.0	July 50 5	Jan. 72 0	21.5	18 2	105 25	38.5	May 3 9	Feb. 2.4	5 0	76	7
San Jorge	400	60 8	June 49 5	Jan. 72 6	23 1	23.2	103 22	40 9	Apr. 4 6	Feb. 2 2	4 5	. .	. .
Argentina													
Buenos Aires	72	61.0	July 48 9	Jan. 73 6	24.7	13 0	103 28	37.2	March 4.4	July 2.2	4.6	77	14
Corrientes	256	71.7	June 61 6	Jan. 81 6	20.0	20.3	112 31	48 1	Apr. 5.7	Aug. 1.5	4 5	70	0
Mar del Plata	82	56 6	July 46 8	Jan. 67 4	20 6	16 7	103 22	29 8	March 3 2	Aug. 1 8	. .	76	. .
Bahía Blanca	49	59.7	July 46 6	Jan. 73 8	27.2	22.6	108 18	20.8	March 2.7	July 1 0	4 4	63	18
STM *Climate of South America*													
Chile													
Valparaiso	135	57.7	July 52 3	Jan. 63 7	11 4	14 8	94 36	19 6	June 6 0	Jan. 0 01	5 2	73	15
Santiago	1703	56 5	July 46 0	Jan. 67 3	21 3	27.4	99 24	14 4	July 3 4	Jan. 0 03	4.0	69	14
Talca	322	58 2	June 46.8	Jan. 70 6	23 8	26.2	100 23	28 0	May 6.7	Feb. 0 2	4.2	70	17

above 100° are frequent. Only once in forty-seven years has a temperature below freezing occurred. The winters are like those of Tampa, Florida. The rainfall of forty-eight inches is well distributed, except for a moderately dry period in winter. Rainfall and temperature conditions are similar to those of the Gulf States of the United States, except that the winters are about 10° warmer and there are no cold waves. This is the cotton-producing region of Argentina.

South of the Rio de la Plata, both temperature and rainfall decrease rather rapidly. Between Buenos Aires and Bahía Blanca there is an area about 450 miles long and nearly as wide in which three months have a mean temperature below 50°, and in which the annual rainfall is between twenty and thirty-five inches. The climate of this region resembles that of east Texas, and in both cases there is a slow transition westward into a steppe climate. Bahía Blanca has about the same mean annual temperature as Oklahoma City, but its climate is marine rather than continental; the warmest month is 7° cooler than at Oklahoma City, and the coolest month is 11° warmer. Thus Bahía Blanca has a subtropical climate, but because of its cold winters Oklahoma City must be classed in an intermediate type. Freezing temperatures have occurred at Bahía Blanca, however, in each of the six coldest months.

As in Uruguay and northeastern Argentina, winter is the season of least rainfall. The maximum usually occurs in autumn (March and April), but there is little difference between the monthly amounts from October to April. Traveling cyclones and anticyclones are important in relation to the weather of this region, but convective rising of air is a major factor in summer. This level grassy plain is devoted largely to cattle raising and the production of wheat, corn, and flax. Frosts are rather too frequent for the profitable development of subtropical agriculture.

The Mediterranean Climate of Chile (STM)

In the middle of the elongated nation of Chile, between latitudes 31° S. and 39° S., there is a typical dry subtropical or Mediterranean climate, very similar to that of California, which is in corresponding northern latitudes. The topographic features of the two regions are also much the same. Each has a narrow strip of

plain along the shore terminating in a low coastal range of mountains with short valleys opening to the ocean; a long level central valley between the coastal range and the high mountain system forms the eastern border of the area. Each merges into a warm steppe and desert region on its equatorward side and into a cool humid marine (IM) climate on its poleward side. Each comes under the influence of the prevailing westerlies in midwinter, and each has most of its rainfall during that season; in summer each is in the subtropical belt of high pressure and is almost rainless. In both cases temperature and rainfall are influenced by relatively cold ocean water offshore which comes from higher latitudes.

Temperature

Valparaiso, the seaport, and Santiago, in the interior valley, are in about the same latitude, numerically, as is Los Angeles. The mean annual temperature at Valparaiso is 5° or 6° lower than at Los Angeles or San Diego, and 1.5° higher than at San Francisco. The inland city of Santiago is 1,300–1,600 feet higher than the valley cities of California, and is 5° cooler in summer than Sacramento and 13° cooler than Fresno and Red Bluff. Its midwinter temperatures are 3–6° lower than those of the California cities. In general, the subtropical portion of Chile has about the same winter temperatures as prevail in similar situations in California, but the summer temperatures are considerably lower. There are two reasons for the cooler summers in Chile: (1) there is cooler water offshore and more continuous wind movement from the ocean; (2) the coastal mountains are not as high or as continuous as the Coast Range of California, and they permit the ocean air to move inland more freely. This Chilean region is also 5° to 10° cooler in summer than the humid subtropical region in similar latitudes on the east coast of South America. Winds are prevailingly from a westerly direction throughout the year in subtropical Chile. Frosts are practically unknown along the coasts, but occur every winter in the interior valleys. Santiago has an average of about one inch of snow per year.

Precipitation

The rainfall regime and amounts are also similar to those of California and to other areas with a Mediterranean type of cli-

mate. There is a distinct maximum from May to August, and from 75% to 85% of the annual rainfall occurs in those months. The midsummer months, December–February, are almost rainless. The rainfall increases southward from scanty at latitude 30° S. (Punta Tortuga, 4.71 inches) to heavy at the southern end of the Mediterranean area (Temuco, 51.15 inches). The winter rainfall is cyclonic, occurring in connection with traveling depressions of the prevailing westerlies, which bring tropical maritime air (warm and moist) from the north. For the rest of the year the winds are out of the eastern end of the Pacific high pressure center, turned somewhat inland because the land is warmer than the water, and therefore becoming southerly or southwesterly winds of decreasing humidity as they move on to lower latitudes and over warmer surfaces. Along the coast there is considerable cloudiness and rather high humidity throughout the year. The central valley has about the same cloudiness and humidity during the winter months, but the summer months are sunny and dry. (Santiago: January cloudiness, 1.8; relative humidity, 56%.)

The climate of this portion of Chile has the charm characteristic of the Mediterranean climates. The weather is pleasant and moderate throughout the year, but with enough difference between day and night and between winter and summer to be mildly stimulating and not monotonous. The crops produced are also the typical subtropical products—olives, oranges, grapes, almonds, walnuts, and deciduous fruits. Irrigation is required for these crops in most of the area, and a constant supply of water during the summer is furnished by the melting snows of the high Andes. This area contains more than three-fourths of the population of Chile.

The Humid Marine Climate of Southern Chile (IM)

At about latitude 39° S. the dry subtropical Mediterranean climate of central Chile changes rather rapidly into a cool, humid, west coast, marine climate (IM) which continues to the southern extremity of the continent, including the island of Tierra del Fuego, which belongs partly to Argentina. The region is narrow, for south of latitude 41° S. the Andes form a single range very near the coast. Again there is a close parallel between the west coast of South America and the corresponding coast of North

America, but the Andes are higher and less broken than the Cascade and Coastal Ranges. The climate of southern Chile closely resembles that of the Pacific coast of North America from northern California to southeastern Alaska. The transition from Mediterranean is more abrupt in Chile than in California; the temperature averages somewhat lower, especially in summer; the rainfall is even heavier, and the cloudiness is more persistent.

The region is under the influence of the prevailing westerlies throughout the year. As has been noted, the westerlies of the Southern Hemisphere are strong and persistent and attended by a regular procession of cyclonic disturbances. These have warm moist winds from the northwest on their eastern sides. As these winds move against the western slopes of the Andes there is almost continuous cloudiness and heavy rainfall; the rainfall is as great as 200 inches in places. This coast is one of the rainiest areas of the globe. In the accompanying table temperature and rainfall at Chilean stations are compared with those at North American stations in similar latitudes. These are all lowland coastal stations in comparable situations, except that the Chilean stations are much closer to the high mountains. The amounts at the Chilean stations are at least twice as great as those on the North Pacific coast. At Valdivia there is a marked maximum in winter and a rather dry summer, as is the case at Eureka and Portland. Farther poleward in each hemisphere there is a more even distribution.

Temperatures at the two sets of stations correspond more closely than does precipitation. Valdivia, it will be noted, has a warmer summer and a cooler winter than Eureka, but Eureka is peculiarly exposed to marine influence and has a remarkably small annual range for its latitude. The other Chilean stations average considerably cooler in summer and somewhat warmer in winter than the corresponding stations in the North Pacific; that is, the climate is more equable and more largely under the control of marine influences. The highest temperature of record is 76° at Melinka and 60° at Evanjelistas. Frosts are infrequent in the northern half; in the southern half the lowest temperatures of winter range from 20° to 30°. There is no warm weather; raw, chilly, moist weather prevails throughout the year, and the relative humidity averages above 80%.

Stations	*Latitude*	*Temperature, °F.*			*Precipitation (Inches)*		
		Year	*Warmest Month*	*Coolest Month*	*Year*	*Wettest Month*	*Driest Month*
Valdivia	40° S.	53	62	46	105	16.9	2.5
Eureka	40° N.	52	56	47	40	7.0	0.1
Melinka	44° S.	50	56	45	125	15.1	6.0
Portland	45° N.	53	67	39	42	6.7	0.6
Evanjelistas	52° S.	43	47	37	119	11.8	8.6
Vancouver	49° N.	49	63	36	59	9.5	1.2
Bahia Felix	53° S.	44	52	36	200	18.9	13.3
Prince Rupert	54° N.	45	57	33	101	13.0	4.1

As a result of heavy precipitation and low summer temperatures, there are many glaciers in the high mountains. The snow line ranges from 6,000 feet at latitude 41° S. to 3,500 feet in Tierra del Fuego. South of latitude 41° S. the hills are heavily forested. There is little arable land, but wheat, barley, and apples are grown. Potatoes are native in this region and now grow wild. In the northern province the most important industry is that of clearing the forest, but stock-raising is also important, and wheat is grown on the cleared land. In extreme southern Chile and in the Island of Tierra del Fuego there are some open grassy plains on the eastern slopes of the mountain ranges, where they are sheltered from the prevailing westerlies. Here the rainfall drops off rapidly to about twenty inches a year. Magallanes (formerly Punta Arenas) has an annual total of 19.4 inches. Tierra del Fuego is an undulating tableland with a fertile soil that produces some barley and oats. The weather is subject to frequent changes, but the skies are overcast most of the time and there is a constant succession of fogs, mists, rains, snows, and gales.

The Steppes and Deserts of South America

South America is on the whole a well-watered continent with a large area of humid climate and with the smallest dry area of any of the continents. Nevertheless, it has in Peru and northern Chile one of the driest areas on the globe—one of the few regions almost completely rainless; this is in marked contrast to the excessive rainfall of southern Chile. It has also in Argentina a considerable

area of semiarid to arid plains, comparable to the intermountain Plateau Region of the United States. In addition there is a small upland low-latitude steppe region in northeastern Brazil. This region is surrounded by the Brazilian savanna, but has a reduced rainfall because of inclosing hills.

The west coast desert of Peru and Chile (STD)

The entire coast line of Peru consists of a narrow coastal plain, ten to forty miles wide, sloping upward gradually to the foothills of the Andes. In Chile, on the other hand, as far south as latitude 40° S., there is a low coastal range of mountains and a long narrow interior valley between these mountains and the Andes. The entire Peruvian coast and both the coast and the interior valley of Chile, southward to latitude 30° S., form one of the driest regions of the world.

Rainfall. The extreme aridity is the combined effect of the oceanic and atmospheric circulations. A portion of the great west-wind drift in the southern oceans turns northward west of South America and carries much cold water into warmer latitudes. At the same time the circulation of air around the subtropical center of high pressure in the Pacific Ocean and toward the interior center of low pressure near the equator results in southwest winds throughout the year along the northern coast of Chile. This air is abnormally cold because it has moved over cold water, and also because it has moved from colder to warmer latitudes. As it moves inland over a warm land surface, its relative humidity decreases and there is no condensation even with a moderate increase of elevation.

Along the coast of Peru the ocean currents and the winds are deflected to the left. The winds become south or southeast trade winds, almost parallel to the coast or somewhat offshore, resulting in an upwelling of cold water close inshore. These winds, which are both cold and offshore, produce no rain; hence, from the northern border of Peru to latitude 30° S. the coastal region is practically rainless. The upwelling cold water near the shore is the cause of some condensation, however. Along the southern half of the Peruvian coast, especially in the vicinity of Lima, the humidity is high, there is much cloudiness, and there are frequent dense fogs, attended by light drizzling rain. The clouds and fogs occur

when wind having a northerly component—therefore warm and moist—is cooled by moving over the cold inshore water. These phenomena begin over the ocean and affect only a narrow coastal strip of land; as soon as the air moves inland the clouds and fog are dissipated by the rising temperature. Note the differences in topography, wind direction, and relative temperature of land and water responsible for the excessive rainfall of southern Chile and for the absence of rain in northern Chile and Peru.

The Gulf of Guayaquil between Ecuador and Peru marks the sudden transition from the moist savanna climate of the coast of Ecuador to the pronounced desert of the Peruvian coast with scarcely any perceptible semiarid transition zone. From this Gulf southward to latitude 30° S. the entire coastal area has an average annual rainfall of less than two inches except at its southern extremity, where it merges into the dry subtropical province. At places the annual total falls to such insignificant and valueless quantities as 0.05 or 0.10 inch. Such rain as does fall comes in irregular, erratic, light showers at long intervals. In some cases months and even years pass without any rain. How rare and uncertain these showers are is indicated by the record of only twenty days of rain in twenty-five years at Iquique and of twenty-six days in sixteen years at Antofagasta. On the other hand, Lima, with an annual amount of 1.90 inches, reports 128 rainy days a year. This is counting the days with foggy drizzle, and evidently does not mean days with 0.01 inch or more, which is the definition of rainy days in the United States. Most of these drizzling days occur in the cooler months, June to October, and give these months an average of 0.20 to 0.40 inch each.

Punta Tortuga (Coquimbo) and La Serena at latitude 30° S. have an average rainfall of four to five inches, falling largely in the cooler months, May, June, and July; this shows the influence of an occasional depression from the south, and marks the transition to the Mediterranean climate of central Chile. The rainfall in this region is largely accounted for by rare but heavy showers. Punta Tortuga has a record of 5.55 inches in twenty-four hours, this one rain amounting to more than the average for an entire year.

Temperature. Temperatures in this desert area are tropical to subtropical in character, but are lower than is normal for the lati-

tude. They are lower than on the east coast of South America or on either coast of Central America and Mexico in corresponding northern latitudes. There again the influence of the great mass of cold water in the south Pacific and of the prevailing winds off that water is evident. The marine influence combines with the low latitude influence to keep the annual range of temperature small—about 9°–13°. In northern Peru temperatures are truly tropical; all months average above 73°, all months have had a temperature of 90° or above, and the lowest temperature of record is 56°. But at Lima, 12° S. and 518 feet above sea level, the warmest month averages only 73°, and there are five months of the year with mean temperatures between 60° and 62°, thus putting Lima in the subtropical category. Southward, the mean temperatures decrease gradually until at Punta Tortuga the highest temperature of record is 80°, the lowest is 37°, and the annual mean is 58°. This is remarkably cool for a sea level station in latitude 30°; at Porto Alegre, Brazil, in the same latitude, the annual temperature is 67°.

No freezing temperatures are recorded anywhere in the lowland area. Temperatures, therefore, are favorable for the growth of tropical and subtropical plants, but the lack of moisture makes most of the region a barren and forbidding desert destitute of vegetation. Fortunately, however, there are a number of permanent streams across the desert which are fed by the melting snows of the lofty Andes. Irrigation has been practiced in Peru since the days of the Incas. The soil is fertile where watered, and the desert is dotted with green and fruitful oases, producing cotton, sugar cane, grapes, oranges, bananas, and other fruits. The southern part of the Chilean desert has similar irrigated tracts, and produces similar crops. The northern portion has a saline soil unsuited for agricultural activities. Its sparse population is largely supported by the production of nitrates for fertilizer and by other mining operations.

The dry climates of Argentina

Argentina extends from latitude 22° S., which is within the tropics, to latitude 55° S., which is the latitude of extreme southeastern Alaska and northern Ireland. It is almost as long as and much wider than Chile, from which it is separated along its entire length by the high cordillera of the Andes. The greater part of

Argentina is in the "rain shadow" of the Andes; that is, the prevailing winds are from the west and as they blow against the mountains, they lose much of their moisture on the western slopes and move down the eastern flanks with increasing temperature and decreasing humidity. As has been noted, northeastern Argentina has northerly or easterly winds and a moderately humid subtropical climate. The western portion of the country north of latitude 40° S. and the entire mainland area south of that parallel is either steppe or desert. It has a general similarity to the arid and semiarid plateau region east of the Sierra and Cascade Ranges in North America from northern Mexico to southern British Columbia.

A large part of northern Argentina west of the humid subtropical region has a steppe climate with an annual rainfall of ten to twenty inches. It extends northward almost to the Tropic and southward to latitude 42° S., and includes a large part of the great central plain of Argentina, the *Pampa,* which is famous for its cattle and wheat. From the western side of this region a narrow semiarid strip extends southward along the foot of the mountains to the southern extremity of the country. Between these strips of semiarid land lies the Argentinian desert area. From latitude 30° it widens southward to include a large part of Patagonia, and between the parallels of 42° and 50° it extends eastward to the Atlantic Ocean.

The Argentine steppe climates (STS and IS)

Temperatures in the semiarid region of northern and eastern Argentina range from tropical in the northern interior to moderately cool on the coast. In the north all months are warmer than 65°, and the annual range is about 14°; at Patagones (latitude, 40°48′; elevation, 105 feet) on the coast, January temperatures average 73° and July temperatures average 46°; there is an absolute maximum of 106° and an absolute minimum of 23°. Precipitation in the region averages ten to fifteen inches a year, with a maximum from February–May (late summer and autumn), and with a minimum in August–October (spring). As in other regions of light rainfall the annual amounts vary greatly; there are series of wet years, and other series of drought years, causing widespread distress.

A weather phenomenon characteristic of the region is known

Dry Climates of Argentina	Elevation (Feet)	Temperature, °F. Mean Annual	Coolest Month	Warmest Month	Annual Range	Mean Daily Range	Abs. Max. & Min.	Precipitation (Inches) Annual	Wettest Month	Driest Month	No. Rainy Days
Semiarid (IS)											
Malargue	4659	51.9	June 36 7	Jan. 66 2	29 5	35.2	98 −10	10.77	March 2.35	Aug. 0 27	35
Patagones	105	59.3	July 46 2	Jan. 73.0	26.8	21 2	106 23	12.04	April 1.61	Aug. 0 39	46
Colonia 16 de Octubre	1827	48.0	July 37 2	Jan. 59 4	22.2	21 6	98 −4	15.75	May 3.27	Oct. 0.43	56
Ushuaia, Tierra del Fuego	39	41.7	June 33.3	Jan. 49.6	16.3	15.7	81 −4	18.85	Feb. 1.93	Aug. 0.91	115
Arid (ID)											
San Juan	2178	63.5	June 48.5	Jan. 77.8	29.3	28.1	115 17	3.48	Jan. 0.79	May June 0.04	11
Choele Choel	456	60.1	July 46.2	Jan. 76 0	29.8	27.4	111 11	8.58	May 1.10	Aug. 0.28	27
Puerto Madryn	46	56.7	July 44.5	Feb. 69.4	24.9	22.7	102 11	5.92	May 0.67	Aug. 0.26	32
Colonia Sarmiento	899	51.7	July 37.4	Jan. 64.8	27.4	21.6	99 −27	4.93	July 0.83	Jan. Dec. 0.16	48
Santa Cruz	39	47.5	July 35.1	Jan. 58.8	23.7	20.2	93 5	5.35	Dec. 0 67	Feb. Sept. Oct. 0.28	49

as the *pampero.* It is a squall wind, often attended by a thunderstorm, occurring along the cold front of an eastward moving cyclone. Over the wide expanse of the pampas the air becomes heated and unstable when slow-moving tropical air overspreads the region. Where this air is abruptly replaced by polar air at the cold front, there are gusty, stormy winds, often raising clouds of dust. This is the *pampero,* and it is of the same general character as the wind-shift squalls and thunderstorms that occur in other parts of the world; here, however, it attains unusual intensity, but not destructive velocities. The *pamperos* occur most often in summer, and are a welcome relief from the heat in spite of the discomfort of the dust. They also extend eastward into the humid subtropical region. Much corn and winter wheat are produced in these semiarid grassy plains, but the country is particularly a cattle country, and the Argentinian *gaucho* is as well known as the cowboy of the western United States.

The semiarid strip along the foothills and lower slopes of the Andes, below 5,000 feet, has a moderate climate, with mild winters and decidedly cool summers. All months average above 32°. Summer isotherms, governed by elevation rather than by latitude, run nearly due north and south. The annual range of temperature is moderate, 20° to 30°, and the daily range rather large, 20° to 35°, increasing with elevation. Temperature conditions are somewhat similar to those of the humid marine climate (IM) of Chile, except that differences between day and night are larger. Mountain streams furnish water for extensive irrigation. In the north the irrigated lands produce much sugar cane, and in the south they produce fruits, alfalfa, and, especially, grapes. The eastern portion of Tierra del Fuego, which belongs to Argentina, also has an annual precipitation of less than twenty inches, and a middle latitude steppe climate with marked marine influences. (See Ushuaia.)

The Patagonian desert region (ID)

The desert area of Argentina includes a large part of Patagonia. It extends north to latitude 30° S. in western Argentina and south to latitude 50° S. It is a plateau reaching to the Atlantic coast between latitudes 42° S. and 50° S., and sloping upward to the semiarid strip at the foot of the Andes. In its northern por-

tion it has a mean annual temperature above 60°, similar to that of the southeastern United States or that of Spain. Temperature decreases southward to an annual mean of about 42° at the extreme south, which is similar to the average in southeastern Alaska and southern Norway. In general, however, the winters are warmer and the summers cooler in this desert than in the other regions just mentioned. Although the desert extends into lower middle latitudes, and although temperatures above 100° occasionally occur in its northern half, it is neither a hot desert nor continental in its temperature ranges. In its warmest portions midsummer temperatures average lower than in the central valleys of the United States, and in its coldest portion midwinter temperatures are higher than in St. Louis or New York City. All months average above freezing. The region is not, therefore, a forbidding one in the matter of temperature.

Moreover, it is not a barren desert like portions of Peru and northern Chile. The rainfall ranges from three to ten inches, and is sufficient with the moderate temperatures that prevail to support a sparse growth of coarse grasses and shrubs. In the river valleys a more abundant and nutritious vegetation prevails and supports large numbers of sheep. The region is not suited for cattle, but sheep-raising is the major industry in the greater part of the arid area. There are fertile, irrigated patches in some of the river valleys which produce cereals, alfalfa, and various fruits. The southern half is under the permanent influence of the stormy westerlies, and strong winds prevail. These vary in direction with the passage of the cyclones, but they are predominantly from a westerly direction.

CHAPTER XVI

Humid Tropical and Subtropical Climates of the East Indies, the Philippines, and Southern Asia

Europe and Asia form a single land mass which is by far the largest continuous land area of the globe. At Singapore it reaches to within 2° of latitude of the equator, and in the peninsula of Taimyr in northern Siberia it extends beyond latitude 77° N. From the coast of Portugal eastward to Bering Strait is a continuous land mass through 200° of longitude. The shortest distance between these places is therefore westward from Portugal across the Atlantic Ocean and North America. The Arctic Circle from the northern coast of Norway to the Bering Strait region is over land for 175° of longitude, almost half of its length, and the parallel of 48° N. latitude is a land parallel from Brest, France, to Sovetskaya, Siberia, on the northern arm of the Sea of Japan—a longitudinal distance of 145°.

Europe and Asia will be treated as one continent, *Eurasia,* since there is no natural climatological boundary between them, and since several of the climatic types extend continuously across the political boundary. The important nearby island groups are also included. These are, in particular, the British Isles on the west, and Japan, the Philippines, and the East Indies on the east. Some of the latter are more closely related climatically to Australia than to Asia, but they are grouped together for convenience. In this sense, therefore, Eurasia reaches from 10° south of the equator to 10° north of the Arctic Circle. It includes twelve of the fourteen major climatic types of the world. It lacks only the tropical highland and the polar icecap types, and it is probable that some of the islands in the Arctic Ocean north of Siberia approach the glacial icecap condition.

General Climatic Features of Eurasia

In considering the general climatic features of the continent, its great area in middle and high latitudes is of primary importance. All but a small percentage of its area lies between the

Tropic of Cancer and the Arctic Circle. It is of great longitudinal extent throughout this zone, the broadest portion being about the middle, between latitudes 45° N. and 50° N. The vast interior of the continent is therefore subject to extreme continental influences. The continental character of the climate is especially marked in northeastern Siberia. The stations in the valleys of the Lena and Yana rivers have the lowest winter temperatures and the greatest annual ranges of temperature ever observed. The continental conditions extend to the Arctic coast because the Arctic Ocean is ice-covered most of the year and has little ameliorating effect on the climate.

Another striking feature of the continent which is of great climatic significance is the irregular nature of its western and southern coasts; these coasts are characterized by numerous large bays and seas extending far inland and separated by large peninsulas. An enumeration of these peninsular areas is sufficient to indicate their historical and climatic significance: Scandinavia, Denmark, the Iberian Peninsula, Italy, Greece, Asia Minor, Arabia, India, and the Siamese Peninsula. These are nine great areas, more or less nearly surrounded by water and subject to the modifying influences of water surfaces. In addition, many of these peninsulas have secondary peninsulas, greatly increasing the coastline. Of course, the climate of the island groups is also much influenced by the surrounding oceans.

The existence of such a long coastline and of such deep indentations would alone account for a large area of land subject to marine influence, but there are other causes which increase the area so affected. First, the prevailing winds are from the west and southwest along the coast of Europe, and there are no effective transverse mountain barriers to prevent their penetration inland. Such north-south mountain ranges as exist are low and have numerous gaps and notches. The mountain systems with an east-west trend help to guide the air inland. Hence, a west coast marine climate extends inland to the eastern borders of Germany. Second, the waters of the northeast Atlantic are abnormally warm, especially in winter, because of the drift of warm water from the southwest; the presence of this warm water in the northeast Atlantic contributes to the extension of mild winters far into the interior of Europe. The climate of the Mediterranean Region is also partly marine, and the climates of India and eastern Asia are

greatly modified by inflowing air from the oceans during the summer monsoons.

Another important feature of the continent is the great extent of mountains and highlands and their largely east-west trend. There is a connected series of highlands from Spain to the Black

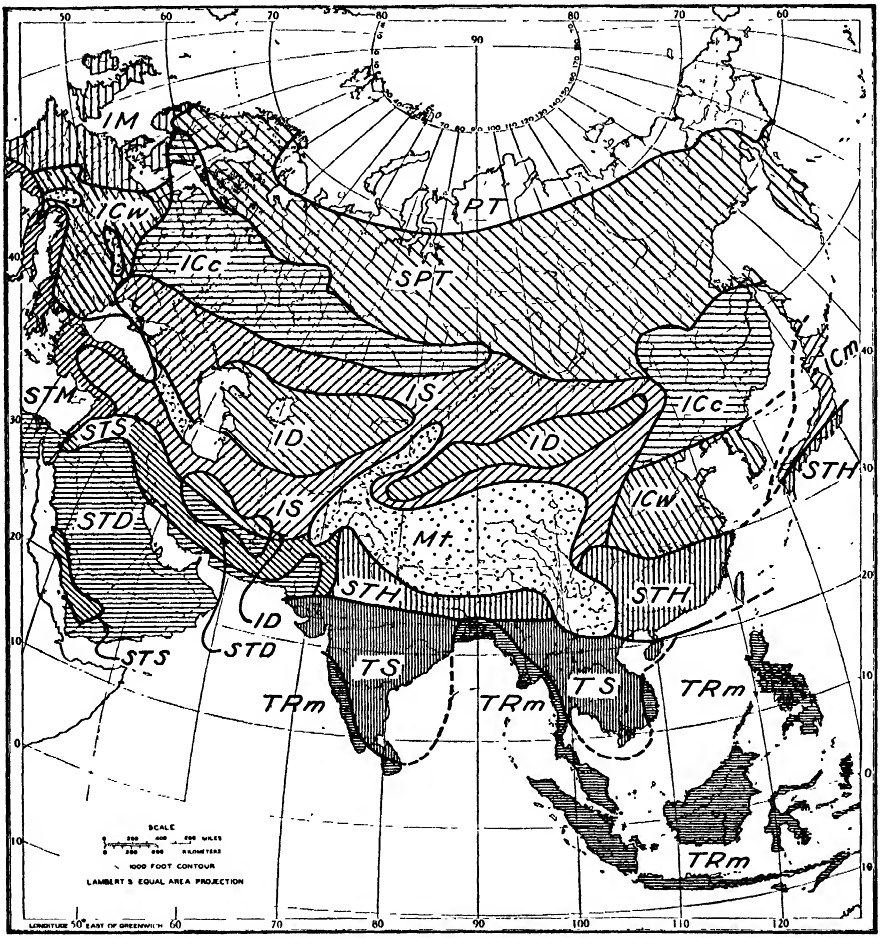

Fig. 71—Climates of Asia.

TRm—Tropical Rainy (monsoon subtype).
TS—Tropical Savanna.
STS—Low Latitude Steppe.
STD—Low Latitude Desert.
STH—Humid Subtropical.
STM—Mediterranean.
IS—Middle Latitude Steppe.
ID—Middle Latitude Desert.
IM—Humid Marine.
ICw—Humid Continental (warm subtype).
ICc—Humid Continental (cold subtype).
ICm—Modified Continental.
SPT—Taiga.
PT—Tundra.

(Base map by permission of the University of Chicago Press.)

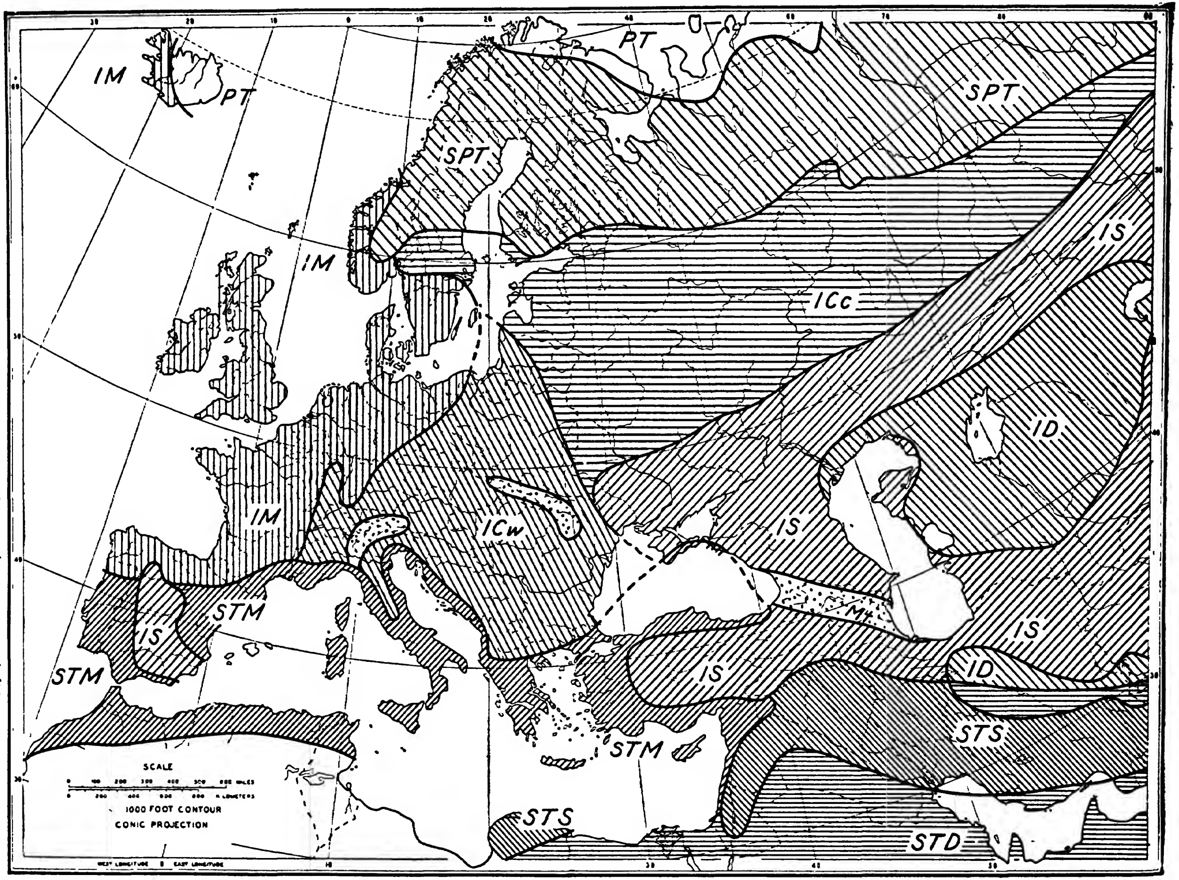

FIG. 72—Climates of Europe.

STS—Low Latitude Steppe.

STD—Low Latitude Desert.

STM—Mediterranean.

IS—Middle Latitude Steppe.

ID—Middle Latitude Desert.

IM—Humid marine.

ICw—Humid Continental (warm subtype).

ICc—Humid Continental (cold subtype).

SPT—Taiga.

PT—Tundra.

(Base map by permission of the University of Chicago Press.)

Sea (Pyrenees, Alps, Carpathians, and Caucasus), and in Asia there are the Himalayas and the associated highlands. These mountain systems act as climatic barriers, and they also happen to correspond in latitude, approximately, with the natural climatic division marked by the subtropical belt of high pressure. Thus there is a rather sharp division between the tropical and subtropical climates south of the mountain systems and the colder climates north of them. Eurasia offers the most extensive examples anywhere in the world of continental, marine, and mountain climates.

Pressure distribution

In January (see Fig. 13) the pressure in Eurasia and adjoining oceans is characterized first by a large and strongly-developed anticyclone covering all of central Asia and centered over Outer Mongolia, and second, by two deep centers of low pressure. One of these is in the vicinity of Iceland and southern Greenland, and the other is in the Bering Sea. These are the *Iceland low* and the *Aleutian low.* This development of strong pressure gradients results from the marked contrast in winter temperature between the extremely cold air of interior Asia and the relatively warm air over the north Atlantic and north Pacific oceans. The result is a steadily outflowing stream of cold dry air across eastern and southern Asia. This is the winter monsoon. It is a northeast wind in southern Asia and a north or northwest wind in eastern Asia north of latitude 30° N. Note that there is a continuous pressure gradient from central Asia southward across the equator to the low pressure belt of the Indian Ocean and northern Australia.

This same pressure distribution results in southwesterly winds over most of Europe which is west of the center of high pressure, but there is an exception in southwest Europe. The subtropical ridge of high pressure persists across the Atlantic and into Spain, separating the prevailing westerlies from the northeast trades, and, in conjunction with a secondary low pressure area over the warm Mediterranean, produces northeasterly to easterly winds on the north coast of the Mediterranean Sea.

Traveling barometric depressions (cyclones) occur with great frequency in the north Atlantic in winter. They cross the ocean from America or form on the southern periphery of the Iceland low, and move for the most part in a northeasterly direction across

western Europe. They are attended by rapid changes of wind direction and air mass. Tropical maritime air masses are brought by the southerly winds on the front of the advancing lows, and are followed by northerly winds and polar air masses on the north and west sides of the lows. There is often precipitation at the surfaces where the differing air masses meet. Thus the greater part of Europe north of the Pyrenees and the Alps has a cyclonic climate, as does much of North America, but it is not as cold in winter or as hot in summer as are corresponding latitudes in central and eastern United States and southern Canada. The reason for the difference is the great expanse of warm water west and north of Europe as contrasted with the extensive cold land areas from which the air moves across the United States and Canada, from the Rocky Mountains to the Atlantic coast.

These cyclonic depressions of winter seldom penetrate into interior Asia, but die out under the influence of the great winter anticyclone over inner Asia. The anticyclones that follow the traveling depressions across the Atlantic frequently stagnate over Europe and take on a character similar to that of the Great Basin highs of western United States. For these reasons, the greater part of Asia north of the Himalayas is characterized by uniform, quiet, cold, dry weather in winter. At this season cyclonic depressions develop in the Mediterranean Basin and move eastward into southern Asia. These are the source of almost all the rain of the Mediterranean and Black Sea areas.

In summer (Fig. 15) the pressure distribution changes markedly. Under the influence of the summer heating and consequent expansion of the air, the great anticyclone of the continental interior is replaced by a low pressure area covering all of Asia. The center of this low is somewhat south and west of the winter center of high pressure. Simultaneously, the Iceland low is much weakened and the Azores high greatly strengthened. Under these pressure conditions strong and steady inflowing winds develop in southern and eastern Asia. These are the summer monsoons. They move inland from the Indian Ocean across India and southeast Asia as southwest winds, and they cross the East Indies, the Philippines, and Japan and move into China and Siberia as south or southeast monsoons, maintaining the cyclonic circulation about the center of low pressure.

The pressure gradient is completely reversed from winter to

summer. In summer the gradient is continuous from the subtropical belt of high pressure of the Southern Hemisphere *northward* into Asia, and the air travels to the north over a broad expanse of equatorial and tropical water, arriving over the land as a warm, moist current and producing a summer maximum of precipitation. The Azores anticyclone includes southwest Europe in summer, giving southwest winds and mild, moist, maritime air in northern Europe and dry northerly winds in the Mediterranean region. In consequence, northern Europe receives considerable rain in summer, but the Mediterranean region is almost rainless during the summer months.

Typhoons

The western Pacific Ocean off the coast of southeast Asia is one of the regions of most frequent occurrence of tropical cyclones (typhoons). These destructive storms originate some distance at sea and move westward. Many of them move over the Philippine Islands and into the China Sea. Some of them cross Borneo, Sumatra, and the Malay Peninsula, and enter the Bay of Bengal. Others originate in the Bay of Bengal or the Arabian Sea, and travel in a northerly or northwesterly direction. All these storms soon cease to be destructive after they move inland, but they occasionally cause immense damage and large loss of life over the islands and along the coasts. They are attended by high storm tides, and the devastation and loss of life are often due as much to flooding of lowlands as to the hurricane wind velocities. Typhoons are attended also by torrential rains.

In the western Pacific region typhoons occur most frequently in summer and autumn (July–November), the season when the doldrum belt of light winds is farthest north. They are less frequent in May, June, and December, and are rare, but not entirely unrecorded, from January to April. Within the area as a whole, the average number of such storms is twenty to twenty-five a year. In the Bay of Bengal there is an average of about two a year, and in the Arabian Sea about one a year. In these northern arms of the Indian Ocean the greatest number of storms occurs in November, and there is a secondary maximum in May or June. These are the monsoonal transition periods of light, variable winds. The presence of quiet air over abnormally warm tropical waters at some

distance from the equator seems to be a necessary condition for the development of these violent storms.

Temperature

As a result of the warm, moist winds from the abnormally warm waters of the north Atlantic, the winter isotherms of Europe, including even Russia and northwest Siberia, trend for long distances in an almost north-south direction. The January isotherm of 30° follows the western coast of Norway from the Arctic Circle to its southern extremity, and the 40° isotherm cuts straight through Great Britain from north to south and halfway through France. It is evident that exposure to oceanic influences is more important than latitude in controlling temperature in these regions. The tendency prevails in all months, but to a less marked degree in summer. At this season the isotherms trend from southwest to northeast. These conditions resemble those along the Pacific coast of North America, but there are two notable differences. First, on the American coast the north-south trend is more pronounced in summer than in winter because of the presence of abnormally cold water close in. Second, in North America the mountain systems confine the marine influence to a narrow coastal belt. The result is that all of Europe has a mild climate for its latitude—warmer winters and cooler summers than corresponding latitudes in North America, for example. The January isotherms of 30° and 40° extend about 5° of latitude farther south in interior United States than in interior Europe. In Europe a July mean temperature of 80° occurs only in isolated areas in the Mediterranean basin; in North America July temperatures average above 80° over a large area of southern and western United States, extending northward to latitude 45° N. in the Great Plains.

Passing eastward into Russia and thence into Asia, the marine influence is still evident in western Siberia, coming in this case directly from the Arctic Ocean (Barents Sea), which receives much heat from the Atlantic drift of warm water. For the remainder of Asia the isotherms are approximately east-west lines, indicating markedly continental conditions without transverse barriers. Along the immediate coast of the Pacific they turn somewhat northward under marine influence, but the climate even along the coast is mainly continental. In winter the temperatures decrease

rapidly northward, culminating in the cold pole in northeast Siberia. In summer the temperature gradient is much less, and the July isotherm of 50° extends to the Arctic Circle in northeast Siberia, as it does across the Bering Strait in Alaska.

Precipitation

As a consequence of the same marine influences that control its temperature, western and central Europe, except for a large part of Spain, is on the whole fairly well watered, having in the main from twenty to sixty inches of rainfall per year and no desert or semiarid areas. The areas receiving sixty inches or more are small, and are confined to the western slopes of mountains or hills. More than half of the region has between twenty and thirty inches. The precipitation is largely cyclonic in its immediate origin, but along the west coasts and the west slopes there are frequent drizzles which are orographic in nature. The time of maximum rainfall is irregular, tending to an autumn or winter maximum on the coasts and a summer maximum in the interior.

From northern Sweden across much of European Russia and thence across the whole of Siberia and northern China to within some 500 miles of the Pacific, the rainfall is mostly less than twenty inches, and there are large areas with less than ten inches a year. These great plains and plateaus of central and northern Eurasia are far from the sources of moisture, and are largely steppe and desert regions. Such rainfall as does occur is largely in the summer months; the winter precipitation is so light that ordinarily a deep snow cover does not accumulate, despite the absence of much thawing weather during the winter months. Southwest Asia, which is in the general region of the subtropical belt of subsiding air, and which receives dry northerly continental winds, is also largely steppe or desert. India, southeast Asia, the island groups, and the Pacific coast northward to latitude 50° receive moderate to heavy rains during the summer monsoons. Amounts of twenty inches extend inland to central China, Manchukuo, and southeast Siberia. Western Japan and certain east coast areas in southeast Asia receive rain also during the winter monsoon.

The climatic conditions of Eurasia are various and complex, but the large influences controlling the general nature of the climate are: (1) the size and latitudinal position of the continent, (2) the

direction of the mountain ranges, (3) the warm water and westerly winds of the Atlantic, and (4) the changing pressure distribution over the interior and the resulting reversal of wind direction.

The Tropical Rainy Climates of the East Indies (TR).

The densest population areas of the world are in certain portions of the humid tropical and subtropical regions of Eurasia; among these areas are Java, the Ganges Valley, southern China, and southern Japan. These are predominantly agricultural populations, and the fact that the land is able to support as many as 500 persons per square mile is evidence that the climate is exceedingly favorable for the growth of vegetation. It is only where climate, soil, and topography are particularly suitable for the intensive cultivation of rice as the principal crop that such dense agricultural populations exist.

The tropical rainy (TR) climate is a climate of continuous summer and abundant rainfall, and hence, a year-long growing season. The characteristics of such a climate as exemplified in the Western Hemisphere have been discussed in previous chapters. It has been noted that the Caribbean tropical rainy region is in the trade wind belt and has a trade wind variety (TRt) of the tropical rainy climate, which differs somewhat from the equatorial variety (TRe) found in the Amazon Basin and the Guianas. The Asiatic region having the same general type of climate (TR) is all within either the trade wind belt or the doldrum belt, but in this region the usual circulation for the latitude undergoes considerable modification. Instead of the typical trade winds almost constant in direction, we find the seasonally-reversing monsoon winds. Hence the climate differs somewhat from both the equatorial and the trade wind varieties, and is designated as the monsoon variety (TRm) of the tropical rainy climate.

In the Eurasian area this monsoon subtype prevails throughout the East Indies and the Philippine Islands, in a part of the east coastal plain of Indo-China, in the Malay Peninsula, on the west coast of Burma, in the lower Ganges and Bramaputra Basins, on the southwest coast of India (Malabar Coast), and in the southern third of the island of Ceylon. A great number of small islands is included. These regions have a latitudinal extent from about 11° S. in New Guinea and Timor to about 20° N. in the Ganges-

Bramaputra region. Sumatra, Borneo, and Celebes are intersected by the equator; Java, Timor, and New Guinea are entirely in the Southern Hemisphere; the Philippines and the mainland areas are entirely in the Northern Hemisphere.

Because they are comparatively small land areas in the midst of warm, tropical waters near the western shore of a great ocean, the East Indies are continuously enveloped in hot and humid air masses. Each of the larger islands consists of a central mountain or highland area surrounded by coastal lowlands, and the movement of the moist air against these mountain slopes produces very heavy precipitation.

Moreover, the seasonal change in wind direction makes one side of the mountain ridges the windward side for a part of the year, and the other slope the windward side for the remainder of the year. Hence, practically all portions of the islands have copious rainfall. The mountains help to guide the surface winds, and consequently there are numerous local variations in the direction of the wind which are due to the local orientation of the slopes. Chiefly because of differences in latitude and longitude, there are also considerable differences in the time of appearance and duration of the monsoons. In general, however, during the winter or low-sun season of the Northern Hemisphere, the winds are from the northeast north of the equator, becoming north or northwest in the Southern Hemisphere. In July and August they are typical southeast trades across the islands south of the equator, and become southwest monsoons when they move into the Northern Hemisphere. The spring and autumn months are transition periods in which the wind movement is light and variable.

The mean annual temperature of the lowland areas is about 80°, and the range between the warmest and coolest months is only 2° to 5°, from about 82° or 83° for the warmest month to about 78° or 80° for the coolest month. Daily maxima exceed 90° throughout the year, and minima are rarely below 70°. Hence, as far as temperature is concerned, there are no seasons. The most uncomfortable seasons of the year are the moist, sultry, oppressive transition periods of uncertain wind movement. Since all of the larger islands have highland areas, it is possible to escape the oppressive heat of the lowlands by resorting to higher elevations for a period, for there is a well-marked decrease of temperature with

elevation. The hot lowland zone of truly equatorial climate extends to an elevation of about 2,000 feet. From 2,000 to 4,500 feet, there is a zone of moderate heat, still tropical but with temperatures some 10° lower than on the plains, and invigorating to those acclimated to the lowlands. There are small mountain areas above 4,500 feet in which a tropical highland climate (TH) prevails.

The East Indies are one of the very wet regions of the world, and numerous local districts receive more than 250 inches a year. On the other hand, there are small areas with less than sixty inches. The greater portion receives from eighty to 150 inches a year. For reasons previously mentioned there are great variations, not only in the total annual amount, but in its distribution throughout the year. The rain falls in heavy downpours attended by lightning and thunder. In places the number of thunderstorms exceeds 300 per year. There is much clear weather between the torrential rains, and cloudiness is not excessive. There is a greater percentage of sunshine and a much greater total number of hours of sunshine than in northwest Europe or on the western coast of British Columbia.

Sumatra

This island lies athwart the equator and has slight temperature changes. It also lies athwart the monsoons, but contrary to the usual rainfall regime in monsoonal lands, it has heavy rain in all months. (The reasons for this are noted in the following paragraph.) A rather lofty chain of mountains extends from northwest to southeast throughout the island's length. The mountains are bordered by a narrow coastal plain on the west and by large alluvial tracts on the east. These tracts are narrow in the north, but broaden to 170 miles in the south. Much of the eastern coast, especially in central and southern portions, is dotted with mangrove swamps, and is unhealthful and almost impossible for habitation by the white races. Temperature and humidity are high at all seasons, the former ranging from about 77° in January or February to 80° or 81° in the spring and autumn months of changing winds.

During the winter season of the Northern Hemisphere the northeast monsoon, attended by heavy, orographic rains, blows

against the north and northeast coasts of Sumatra. South of the equator these winds become northwest monsoons, giving heavy rain also on the west coast. In the Asiatic summer the southwest monsoon impinges on the west coast, and the southeast monsoon, or trade wind of the Southern Hemisphere, blows against the south and southeast coasts, again giving heavy rain on both sides of the island. Thus most of Sumatra lacks the dry season typical of monsoon climates. The entire western slope has a rainfall of more than 100 inches, mostly from 125 to 185 inches, with heavy rain in all months. Note that the least monthly amount at Padang (Fig. 73) is more than ten inches. Most of the east slope has amounts of eighty to 100 inches. There are areas in the central plateau region with mountains on both sides where the prevalence of rank grasses instead of forests indicates a considerably smaller total rainfall; exact data, however, are lacking.

Most of Sumatra was originally covered with valuable tropical forests of a great variety of trees. The cultivated areas produce coffee, rice, tea, tobacco, palm oil, citrus, and tropical fruits. The hot, moist climate is favorable for the production of rubber, and the rolling uplands are suited to the production of coffee and tobacco. Because of the absence of a dry season, sugar cane is not a major crop.

Java

Java is a long, narrow island running nearly east and west, with a highland system near its southern border. The temperature conditions are similar to those of Sumatra, but the seasonal change is even slighter. At Batavia the annual range is only 1.9°, from 77.9° in January and February to 79.8° in October; the absolute maximum of record is 96°, the minimum is 66°, and the daily range is about 12°. The rainfall is abundant, but averages less than in Sumatra. The greater portion of it occurs from December to March, during the northeast monsoon of Asia which here in the Southern Hemisphere becomes a northwest monsoon. January and February are the wettest months. The southeast monsoon prevails from May to September and is relatively dry, because it has passed over a limited area of warm water since leaving Australia. (Note the dry season at Batavia, Fig. 73.) The rain falls in heavy showers, thunderstorms are frequent, cyclonic storms are rare, and

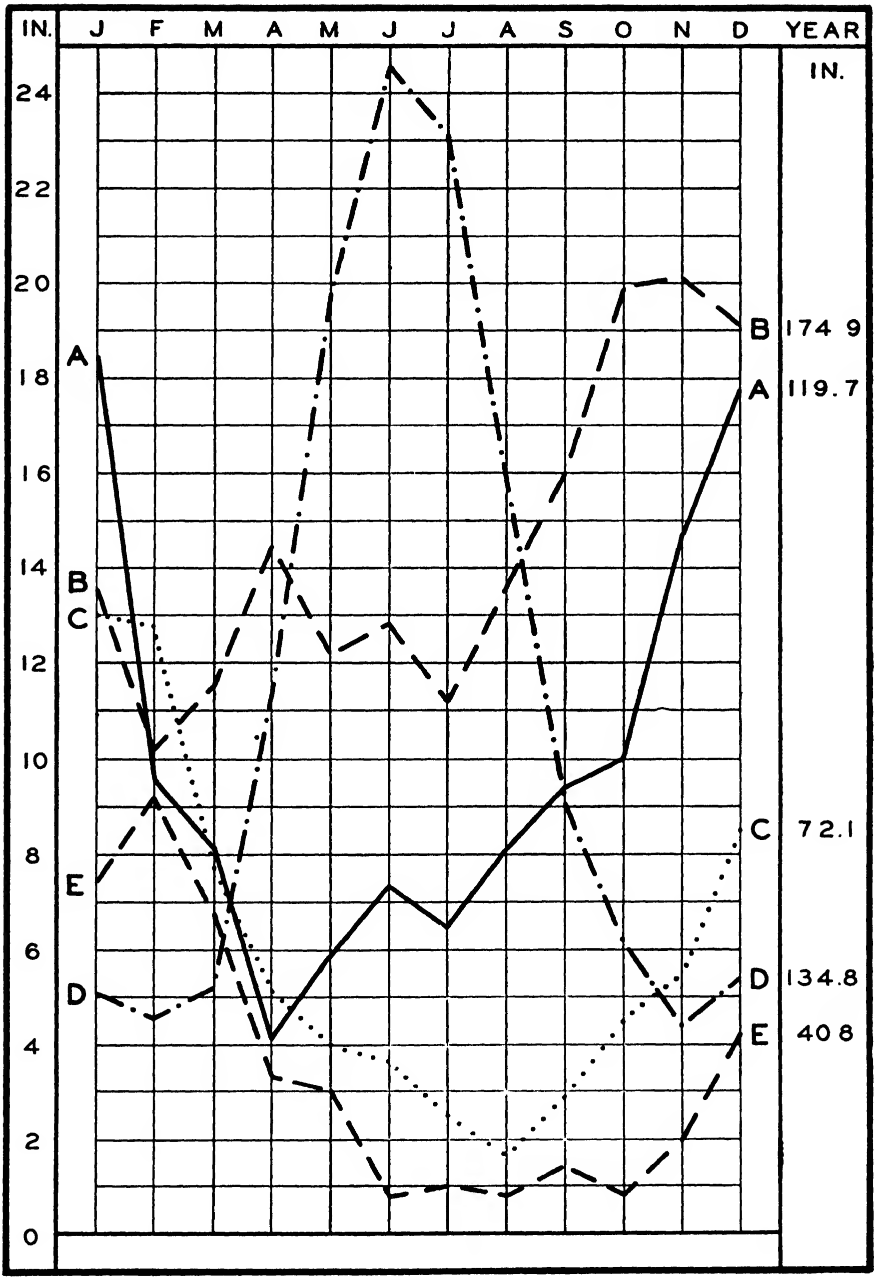

FIG. 73—Average Precipitation. Tropical rainy monsoon climate of the East Indies.
A. Sandakan, N. Borneo. B. Padang, Sumatra. C. Batavia, Java
D. Amboina, Moluccas. E. Port Moresby, New Guinea.

there is much bright, sunny weather. Because of the wind conditions just mentioned, the rainfall is heaviest in the southwest and decreases eastward and on the north slope. Amounts range from approximately 100 inches in the southwest to approximately sixty inches in the extreme east.

The hot lowland zone below 2,000 feet is a tropical jungle region with a seasonal rhythm in rainfall, and produces sugar, rice, rubber, coconuts, cotton, and cinnamon. It supports a dense agricultural population—more than 800 persons per square mile in places. The intermediate zone, between 2,000 and 4,500 feet, is well-suited to the production of coffee, tea, and cinchona. The latter tree is the source of quinine, and Java leads in the production of this drug, although the tree is really native to South America. The mountain regions have dense tropical forests in the wetter, western portion which give way to large areas of teak in the central portions and to open forests in the east. Some of the higher mountain slopes extend into a region of much cloudiness and prolonged drizzling rains, where the tropical trees give place to oaks and chestnuts.

Borneo

This large and rather compact island, crossed by the equator near its broadest portion, has an interior consisting of plateaus separated by several short and rather low mountain ranges trending in various directions. It is rimmed by low alluvial plains with mangrove swamps in many places. It has, therefore, many local climatic variations, but its general type of climate is the same as that of Sumatra and Java—hot, damp, and oppressive in the lowlands, and more comfortable in elevated regions. The entire island has heavy rain, and the greater part of it is sparsely inhabited and covered with dense tropical forest. Climatic data are available only for the cultivated lowland areas. Here the mean temperatures range from 78° to 81°; the minima rarely fall below 70°, and the maxima are rarely above 95°.

The annual rainfall is more than 100 inches over more than half of the island, but drops below eighty inches in a small area on the eastern coast. Rainfall is heavy in all months, but the maximum occurs from October to January, during the prevalence of the winter monsoon of the Northern Hemisphere, which is northeast in

northern Borneo and which becomes northwest in southern Borneo after crossing the equator. The southeast monsoons of the Southern Hemisphere winter are drier, but they bring considerable rain to the south coast of the island. In north Borneo the least rain occurs in April and May in the period of receding monsoons, but is nevertheless in excess of four inches a month. On the west coast, July, which has a mean of more than six inches, is the " driest " month, for then there are frequent southeast offshore winds. Throughout the island most of the rain falls in torrential downpours of short duration, and is often preceded by violent wind squalls. On the west coast few days pass without a shower. There is a great variety of luxuriant tropical vegetation on the island, including palms, spices, and tropical fruits. The climate is well-adapted to the production of rubber and coconuts. Rice, cotton, sugar, coffee, tobacco, and indigo are also grown.

Celebes

The neighboring island of Celebes is, like Borneo, a mountainous island largely covered with tropical forest. Its climate, too, is similar to that of Borneo, except that Celebes is everywhere open to the sea and is distinctly marine. The coastal plain is narrow, generally less than ten miles wide. Owing to its very irregular coast line, it has a complicated rainfall regime. The larger portion is south of the equator and has from eighty to 100 inches of rain, brought mainly by the southerly monsoon. The long peninsular plateau north of the equator has from sixty to eighty inches of rain annually; the rain is largely convectional in character.

New Guinea

This very large island has a high mountain range through its center, and it also has lower coastal ranges. There are both extensive plains near sea level and large plateaus above 3,000 feet. The northwest part of the island has equatorial conditions all year; the annual range of temperature is about 1.5°, the total rainfall is over 100 inches, and all months are wet. The remainder of the island is far enough from the equator to show the seasonal changes of the Southern Hemisphere in a small degree. For example, the annual range of temperature is 4.8° at Port Moresby, Papua, latitude 9° S. On the plateaus the weather is pleasantly cool. Some of the

mountains extend above 13,000 feet and have some freezing temperatures and snow.

TRm *Climate of East Indies*	*Mean Temperature, °F.*				*Av. Precipitation (Inches)*		
	Year	*Coolest month*	*Warmest month*	*Range*	*Year*	*Wettest month*	*Driest month*
Sandakan, Borneo	81.3	Jan. 79.8	May 82.6	2.8	119.7	Jan. 18.5	Apr. 4.1
Pontianak, Borneo	....	...	....	...	126.1	Nov. 15.9	July 6.5
Menado, Celebes	....	....	....	.	103 6	Jan. 18.3	Sept. 3.3
Amboina, Moluccas	79.3	July 77.4	Feb. 81 0	3.6	134.8	June 24.6	Nov. 4.4
Padang, Sumatra	.	.	.	. .	174.9	Nov. 20.1	Feb. 10.2
Batavia, Java	79.0	Jan. 77.9	Oct. 79.8	1.9	72.1	Jan. 13.0	Aug. 1.7
Koepang, Timor		..	...	...	58 2	Jan. 15.8	Sept. 0.1
Port Moresby, New Guinea	80 3	Aug. 77.7	Dec. 82 5	4.8	40.8	Feb. 9.2	Aug. 0.8
Manokwari, New Guinea	.	..	. ..	...	97.3	March 13.1	Oct. 4.2

In general, the rainfall is heaviest during the prevalence of the northwest monsoon from December to March. The season of the southeast trades, May to October, is a relatively cool and dry season in most parts of the island. There are, however, extreme local variations both in the yearly distribution of the rainfall and in its total amount; these variations depend upon the orientation of the shore lines and the highlands to the winds. The southeast trades produce heavy rains on coastal slopes directly athwart their path. Port Moresby, which is on the east shore of the Gulf of Papua, has a rainfall of forty-one inches a year; Kikori, on the northwest shore of the same gulf, has 230 inches, and the maximum amounts fall during the months of minimum at Port Moresby.[1] Yearly totals of 200 inches or more are not uncommon in lowland areas, and

[1] W. G. Kendrew, *Climates of the Continents,* Third Edition (Oxford: Oxford University Press, 1937), p. 169.

amounts are probably much greater in some mountain locations. Dense forests cover most of the island. Tropical vegetation flourishes, but, except for native subsistence farming of the usual tropical food plants, there is little agriculture. A species of cotton native to the island is produced commercially to a limited extent.

Timor

Timor and the neighboring smaller islands are related to northwest Australia in climate and flora. Temperatures are tropical throughout the year, but rainfall is much lighter than in the rest of the East Indies. Rainfall is distinctly concentrated during the mid-summer months of the Southern Hemisphere, December to February; during this time the northwest monsoon prevails, bringing warm, moist air from equatorial seas. May to October is dry under the influence of the southeast trades, which carry air from the arid interior of Australia. Hence the rainfall decreases from west to east. Over most of Timor the annual amount is between twenty and forty inches, but in the extreme west it rises to about sixty inches. At Koepang on the west coast the annual total is 58.2 inches, of which 49.4 inches fall in the four months of December to March, inclusive; only 2.8 inches fall during the five months from May to October.

The Tropical Rainy Climates of the Philippines and Southern Asia (TR)

The East Indies lie wholly within 10° of the equator, but in the Philippine Islands the tropical rainy climate extends northward to latitude 19° N. and in the Ganges Delta to beyond the Tropic of Cancer.

The Philippine Islands

These islands have narrow coastal plains, generally less than ten miles wide, and an interior of mingled highland plains and mountains. The north equatorial current of the Pacific Ocean is on their eastern side, and the notably warm current of the Java and China seas, which has a surface temperature of about 82°, washes their western coasts. Hence, throughout their length, the islands have the heavy rainfall and small temperature ranges characteristic of a tropical oceanic climate. Mean annual temperatures

of 78° to 80° prevail, and the difference between the warmest and coolest months varies from about 4° in the south to 10° in the extreme north. The warmest months are April, May, and June, which have an average temperature of 82° or 83°. The coolest month is January, which has a mean of about 78° in the southern and central portions; this mean decreases to 73° in the north (Fig. 74). At Manila the recorded extremes of temperature are 60° and 100°; the mean annual relative humidity is 79%, and the monthly humidity averages range from 71% in April to 85% in September. The climate is hot, humid, and oppressive.

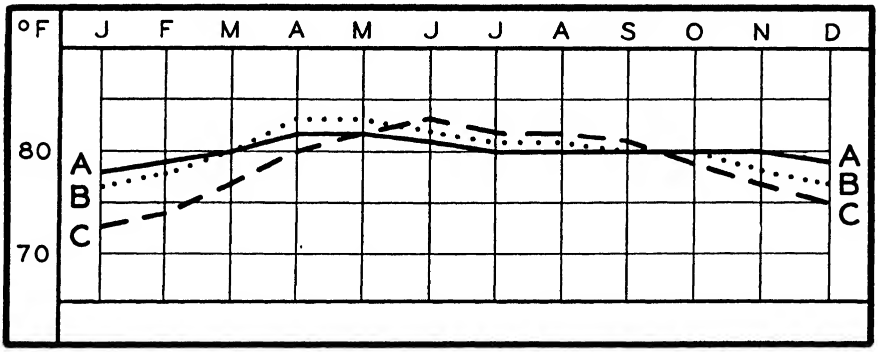

FIG. 74—Average Temperature. Tropical rainy monsoon climate of the Philippines. A. Iloilo. B. Manila. C. Aparri.

In the Philippines both the southwest and the northeast monsoons are attended by heavy rain. The southwest monsoon of summer brings heavy rain on the western slope; the maximum occurs in July, August, and September. (See Manila and Iloilo, Fig. 75.) During the prevalence of the northeast monsoon, the west coast has prevailingly offshore, down-flowing winds, resulting in a dry season. On the other hand, the eastern slopes receive heavy rain with the northeast winter monsoon; the maximum is in October and November in the north (Aparri), and in December and January farther south (Legaspi). The eastern and southern areas also have considerable rain during the prevalence of the southwest monsoon, and accordingly they have no distinctly dry season. Manila and Legaspi illustrate the different regimes; Manila has a total of only 2.07 inches during the three months of January, February, and March, but the rainfall of the driest month at Legaspi is 4.57 inches. The driest parts of the archipelago are the large southern island, Mindanao, and the smaller islands north-

west of it. In this region the annual amount is between eighty and 100 inches; elsewhere the totals exceed 100 inches. The Philippines suffer from more tropical cyclones (called *typhoons* in

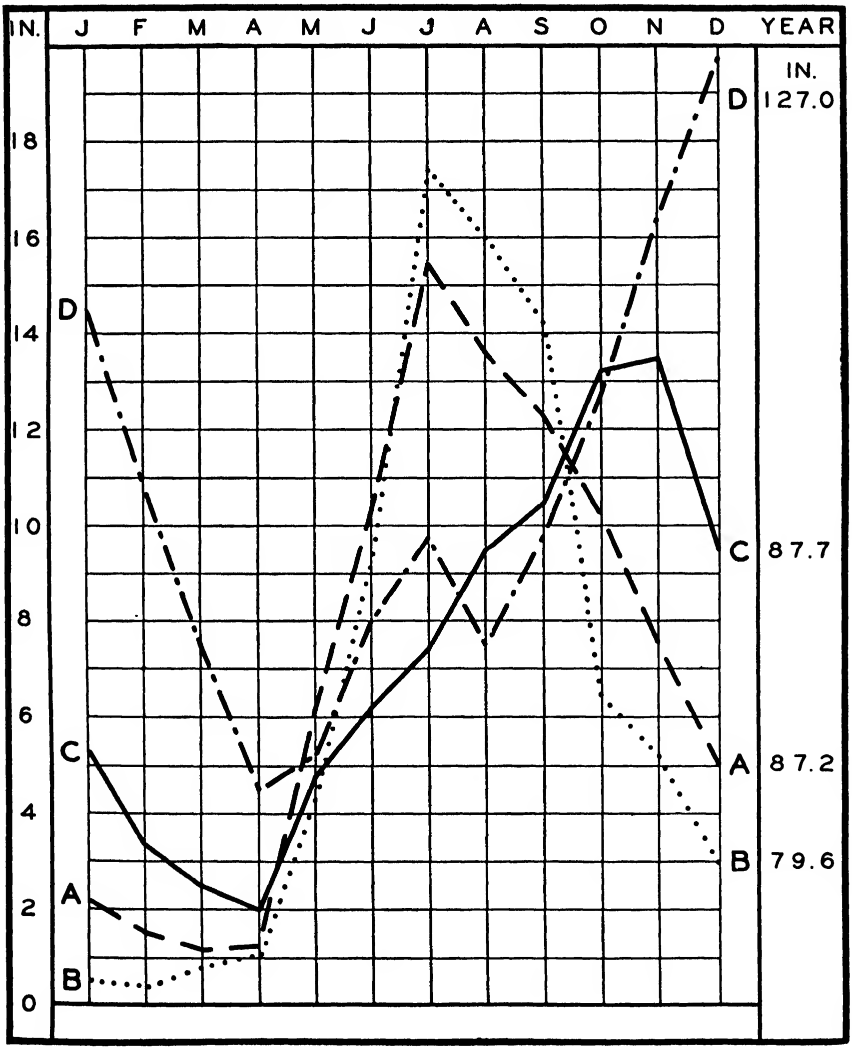

FIG. 75—Average Precipitation. Tropical rainy monsoon climate of the Philippines.
A. Iloilo. B. Manila. C. Aparri. D. Legaspi.

the Pacific area, and locally known as *baguios* in the Philippines) than any other region of the world. An average of more than twenty per year is felt in the islands. They are particularly frequent in the northern portion and during the autumn months, and

they contribute to the heavy rainfall of those months. The autumn rainfall is heavier than that of spring throughout the islands.

The tropical monsoon climate of the western slopes, with a wet growing season and a dry harvest time, is particularly favorable for the growing of such crops as rice, sugar cane, and tobacco. The lowland coastal fringe is suited to coconuts. Abaca, or manila hemp, a valuable rope fiber, is obtained from a native species of banana which is cultivated along the eastern coast.

Annam

Where French Indo-China bulges eastward into the China Sea, a part of the coastal region called *Annam* has a tropical rainy climate similar to that which we have been discussing. (Nhatrang and Hué in table.) Because of some continental influence from the interior, summer temperatures are even somewhat higher than in the Philippines; that is to say, the southwest monsoons are warmed by passage over a considerable expanse of the interior of Indo-China and Siam (Thailand). The winters, particularly in the northern portion, are cooler than in the Philippines, because there is a return current of cool water from the north close inshore along the China and Indo-China coasts. The hot summers and cool winters result in an annual temperature range of 17.6° at Hué, which is a large range for a tropical coastal station.

The rainfall is brought by the northeast monsoon which has absorbed much moisture in its course over warm waters, and which is forced upward as it impinges against the highlands back of the coast. The precipitation is, therefore, seasonal; it is heavy from September to December and light for the remainder of the year, when winds are mostly offshore. The annual total is from 100 to 140 inches, three-fourths of which falls in the four months from September to December. Rice is the principal agricultural product, but rubber trees, coffee, sugar cane, and cotton are also grown.

Malay States and Southern Ceylon

The Malay States are exposed to both monsoons. The northeast monsoon reaches them from the warm China Sea, and produces heavy rainfall as it moves upslope. The southwest winds of summer, although losing some of their moisture in crossing Sumatra, also cause considerable rain. The transition periods are

TRm *Climate of Southeast Asia*	*Mean Temperature, °F.*				*Av. Precipitation (Inches)*		
	Year	*Coolest month*	*Warmest month*	*Range*	*Year*	*Wettest month*	*Driest month*
Philippines							
Appari	. . .	. . . .	. . . .	. . . .	87.7	Nov. 13.4	Apr. 2.0
Manila	79.9	Jan. 76.6	May 83.1	6.5	79.6	July 17.3	Feb. 0.4
Legaspi	80.4	Jan. 78.1	May 82.8	4.7	127.0	Dec. 19.9	Apr. 4.6
Iloilo	. . .	. . . .	. . . .	. . . .	87.2	July 15.6	March 1.2
Annam							
Hué	77.7	Feb. 67.5	June 85.1	17.6	102.0	Oct. 26.3	March 1.8
Nhatrang	80.3	Jan. 75.5	Aug. 84.1	8.6	54.0	Nov. 13.8	Apr. 0.9
Malay States							
Penang	80 2	Dec. 78.8	Apr. 81.7	2.9	107 2	Sept. 16.4	Feb. 3.1
Singapore	79.3	Jan. 77.9	May 80.6	2.7	95.1	Dec. 10.4	May 6.5
Ceylon							
Colombo	80.2	Jan. 79.0	May 82.1	3.1	83.1	Oct. 13.1	Feb. 1.9
W. Burma							
Akyab	78.9	Jan. 69.5	May 85.0	15.5	203.8	July 53.7	Jan. 0.1
Rangoon	79.2	Jan. 74.7	Apr. 85.0	10.3	99.0	July 21.4	Feb. 0.2
Moulmein	. . . .	. . . .	. . . .	. . . .	190.3	July 45.1	Feb. 0.1
Mergui	. . . .	. . . .	. . . .	. . . .	102.3	July 31.5	Dec. 0.6
Ganges Delta							
Calcutta	77.9	Jan. 65.2	May 85.7	20.5	58.8	July 12.1	Dec. 0.2
Dacca	. . . .	. . . .	. . . .	. . . .	74.2	June 13.6	Dec. 0.2
Malabar Coast							
Mangalore	. . . .	. . . .	. . . .	. . . .	128.9	June 38.1	Feb. 0.1
Calicut	79.5	July 76.7	Apr. 83.6	6.9	118.6	June 35.0	Feb. 0.2

doldrum seasons of light winds and local convective thunderstorms. Hence there is rain at all seasons, and considerable local variation in the time of maximum and minimum; the annual total is more than eighty inches, and, in some places, more than 100 inches. (See Singapore and Penang.) Temperatures are similar to those of Sumatra and Borneo. There are heavy tropical forests, and the climate is especially adapted to the production of rubber. Much rice is also grown.

The southern portion of Ceylon is also exposed to both monsoons, and it has a climate similar to that of the Malay States, ex-

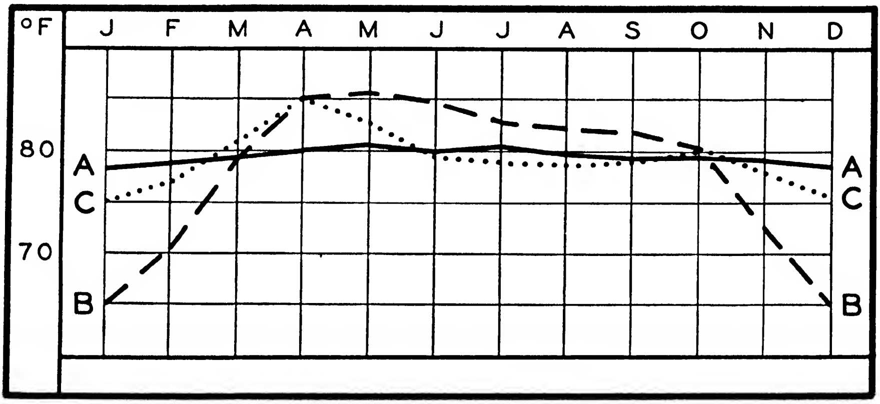

Fig. 76—Average Temperature. Tropical rainy monsoon climate of southern Asia. A. Singapore, Malay Peninsula. B. Calcutta, Ganges Delta. C. Rangoon, West Burma.

cept that in this case the southwest monsoon releases more moisture than does the northeast monsoon after its comparatively short path over the Bay of Bengal. Hence the summer half-year is wetter than the winter half. The northern half of this island has less than sixty inches of rain a year, and there is a long dry season; the climate, like that of the adjoining part of India, is of the tropical savanna (TS) type.

West Burma, Ganges Delta, and the Malabar coast

Two other regions of tropical rainy climate are to be noted. The eastern shore of the Bay of Bengal from the Malay Peninsula to the Delta of the Ganges is bordered by a coastal plain facing southwest directly toward the summer monsoons. This is the west Burma coast. The west coast of India on the seaward slope of the Western Ghats has a similar region similarly oriented. This

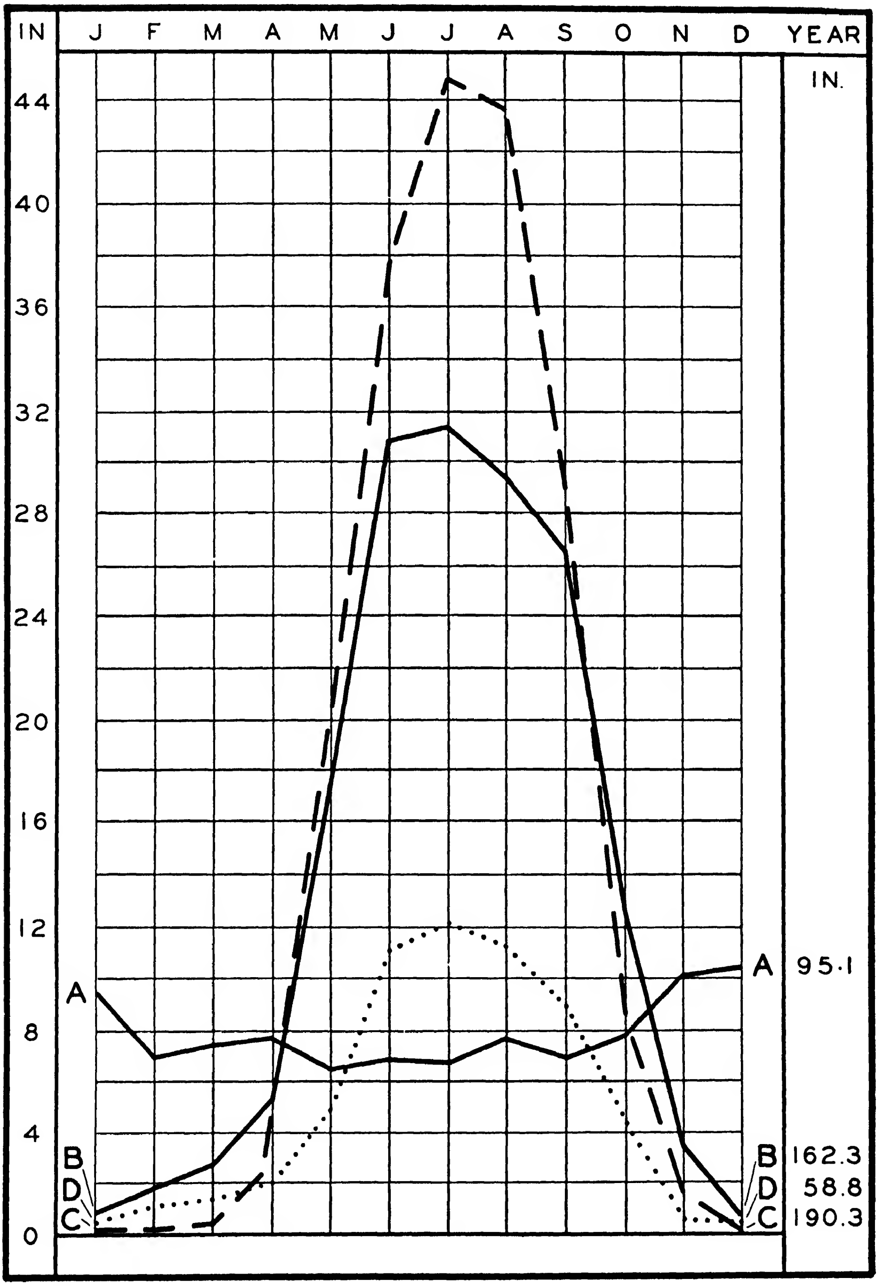

FIG. 77—Average Precipitation. Tropical rainy monsoon climate of southern Asia.
A. Singapore, Malay Peninsula. C. Moulmein, Burma.
B. Mergui, Malay Peninsula. D. Calcutta, Ganges Delta.

is the Malabar coast. In both situations rainfall is heavy during the prevalence of the southwest monsoon, June to September, and light from December to March, while the winds are from the continental interior. (Note the difference between the wettest and

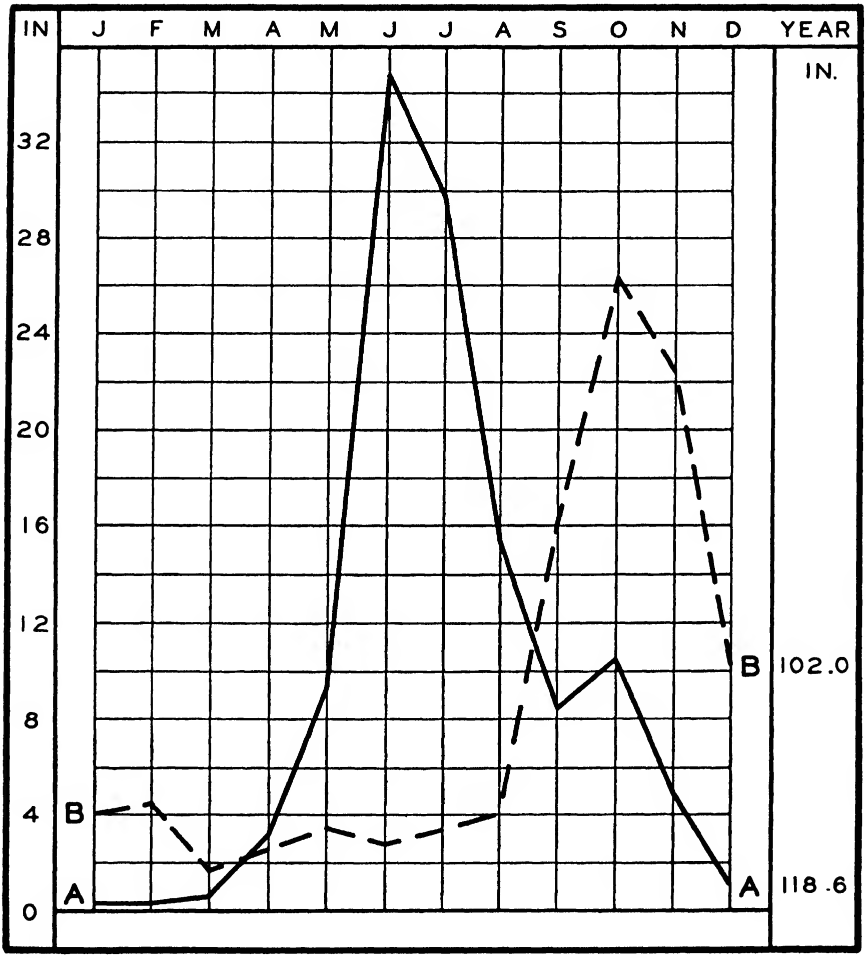

Fig. 78—Average Precipitation. Tropical rainy monsoon climate of southern Asia. A. Calicut, Malabar (W. coast of India). B. Hue', Annam (E. coast, Indo-China).

driest months at Moulmein and at Mangalore.) Despite a conspicuously dry season during the cool months of the northeast monsoon, the total rainfall is sufficient to maintain a permanently moist soil and to support a heavy growth of tropical forest.

In the Ganges Valley this climatic type extends northward to the Tropic of Cancer, its farthest poleward extension anywhere in

the world. Northward from Singapore to Calcutta there is, naturally, an increasing annual range of temperature, especially since the northern portion is subject to the influence of continental air during the winter months. In the north summer temperatures tend to be a few degrees higher and winter temperatures a few degrees lower. Thus the annual range increases from 2.7° at Singapore to 10.3° at Rangoon and to 20.5° at Calcutta. At the latter place the January temperature of 65.2° is at the lower limit for a tropical climate. On the Malabar coast the annual range is about 6° to 10°. Rice is the principal cultivated crop of these regions, especially in the river valleys where flooding is easy. Jute is also an important crop in the Ganges Delta, and tea and spices are produced on the Malabar coast. Some areas produce rubber, but the growth of the trees is checked by the dry season.

The Tropical Savanna Climate of Southern Asia (TS)

The tropical climate with moderate rainfall and a prolonged dry season prevails in the Siamese Peninsula, Burma, and the peninsular portion of India, except in those coastal regions previously classified in the tropical rainy (TRm) type. Northern India and northern Indo-China are not included. The monsoon winds, which are a controlling factor of the tropical rainy climates just described, are also a governing factor in the climate of these regions.

Siam (Thailand) and Indo-China

The major portions of these countries exemplify the tropical savanna type of climate. Temperatures are strictly tropical in the south (see Saigon), but they merge into subtropical in the Tonkin province in northeastern Indo-China. There are still cooler climatic zones in the rugged mountainous region of northwestern Indo-China and northern Siam. The rainfall is moderately heavy, between fifty and seventy-five inches in general, but there is a distinct dry season of several months. Summer and autumn are the wet seasons, winter and spring the dry seasons. At Saigon, sixty-seven inches of rain fall in the six months, May to October, and only ten inches in the remaining six months. Central Thailand has an annual rainfall of sixty inches, forty-eight inches of which fall from June to November. The lowlands are mostly uti-

lized in the production of rice; other products are cotton, rubber, sugar cane, and coconuts. Tea, tobacco, and coffee are grown at the well-drained intermediate levels; cereals and beans are grown in the higher valleys. The rugged mountain areas are well forested. In northern Thailand teak is an important constituent of the forests.

TS *Climate of Southeast Asia*	*Mean Temperature, °F.*				*Average Precipitation (Inches)*		
	Year	*Coolest month*	*Warmest month*	*Range*	*Year*	*Wettest month*	*Driest month*
Indo-China							
Quangtri	.	.	.	...	99 0	Nov. 22.0	Feb. 2.1
Pnom Penh	..	.	.	..	55.8	Oct. 10.9	Jan. 0.2
Saigon	81.9	Dec. 78.8	Apr. 85.8	7 0	77.4	Sept. 13.4	Feb. 0.1
Burma							
Mandalay	80 8	Jan. 68.8	Apr. 89.2	20.4	35.1	May 5.8	Jan. 0.1
India (coastal)							
Bombay	80 6	Jan. 75.5	May 85.8	10.3	72 4	July 24 2	Dec. 0.1
Vizagapatam (Waltair)	81 3	Jan. 73 9	May 86.9	13 0	41.0	Oct. 9.4	March 0.3
Madras	83.1	Jan. 76.2	June 90.0	13.8	49.6	Nov. 13.61	Feb. 0 3
India (interior, peninsula)							
Nagpur	80.3	Dec. 68.1	May 95 0	26.9	46.4	July 13.3	Dec. 0.5
Poona (elev. 1,846 ft.)	75 9	Dec. 68.9	Apr. 83.9	15 0	28 9	July 7.2	Feb. 0.1
Bangalore (elev. 3,020 ft.)	74.5	Dec. 68.7	Apr. 81.5	12.8	35.3	Sept. 6.8	Feb. 0.2

Burma

The cultivated portion of interior Burma consists largely of a series of river valleys running north and south and separated by a series of highlands. A portion of the Irrawaddy Valley is in the rain shadow of the western coastal range, and has less than forty inches of rain (see Mandalay). Elsewhere the total is from fifty

to eighty inches—more as the northern highlands are approached. The wet months are the months of the southwest monsoon, May to October; the remaining six months are dry. December, January, and February, at the height of the northeast monsoon, are almost rainless. The mean annual temperature is about 80°. The warmest month is April or May, in the quiet, clear weather just before the "breaking" of the summer monsoon. At this time the mean temperature reaches 89°, which is several degrees warmer than the temperature which prevails in the tropical rainy regions discussed in the previous section. The coolest month is January, which has a mean between 65° and 70°. The drier part of the Irrawaddy Valley is a mixed crop region, but produces rice under irrigation. In the highlands of north Burma rice and tea are grown below 5,000 feet, and grains and beans above that level. The higher slopes are well-forested, teakwood being the most valuable product. It was in Burma that Kipling saw "the elephants a-piling teak."

India

India forms an outstanding illustration of a monsoon climate in its most completely developed form. The year is divided into four seasons in relation to the monsoon:

1. Cool season, northeast monsoon well-established—January and February.
2. Hot transitional season of variable winds and increasing insolation—March to mid-June.
3. Rainy season, southwest monsoon well-established—mid-June to mid-September.
4. Warm dry season of retreating monsoon—mid-September to December.

During the winter season the continental high pressure area is centered over Outer Mongolia, but high pressure also extends southwestward to Afghanistan and northwest India, and from this region there is a slight gradient southward across India into the southern Indian Ocean. Hence the general movement of air is from a northerly direction. But the highest mountain system of the world separates the plains of India from the cold interior of central Asia. Because the thickness of the cold, continental air

mass is less than the height of these mountains, there is no direct movement of air from inner Asia across the Himalayas. If there were, northern India would have severe cold waves and much colder average winter weather than it does have. Instead, the winter monsoon air that crosses India has its origin in Afghanistan and the southern slopes of the Himalayas. The northeast monsoon over India is a light and shallow current, and its direction is considerably modified by local conditions. It reaches the east coast of the peninsula across the Bay of Bengal, and it penetrates to the interior as a northeast or east wind. On the other hand, it flows down the Ganges Valley from the northwest, and is also northwesterly on most of the west coast and on the seaward slope of the western Ghats.

Composed in the main of cool, continental, descending air flowing outward and toward lower latitudes, the northeast monsoon has rather low humidity and produces little rain. Northern Ceylon and extreme southern India receive considerable rain at this season, and the Ganges Valley is occasionally invaded by a rain-bearing winter cyclonic depression from the west which originates in western Asia or the Mediterranean region. The greater portion of peninsular India, however, has a rainfall of less than one inch for the two months of January and February.

In March, with increasing insolation, the interior warms rapidly, the southward pressure gradient weakens, and the winds become light and uncertain, permitting daily land and sea breezes to develop along the coasts. With advancing summer the gradient is gradually reversed, and winds become southerly and more humid. These conditions continue until about the middle of June. This is a season of intense heat and much sunshine occasionally interrupted by thunderstorms, but precipitation is light except in the extreme southwest. Suddenly, about the middle of June, the southwest monsoon "bursts," and heavy, general rain with thunder and lightning occurs. For three months thereafter the monsoon, charged with vapor from tropical waters, continues steadily at a velocity of ten to fifteen miles per hour. There is, simultaneously, much cloudiness, general rain, and some decrease in mean temperature. Over peninsular India the wind is steadily from the southwest; in the Bay of Bengal it is from the south; deflected up the Ganges Valley, it becomes southeast there.

Although the winds are steady, it does not rain continuously. Rain falls in showers, and rainy spells are interspersed with days of sunshine. Generally the monsoon is regular in its appearance, but there are years in which it is delayed, or in which it is weak or of shorter duration than is usually the case. Such years are years of crop failure, and sometimes there is severe distress and famine, especially in the interior of the peninsula and in the northwest, bordering the semiarid regions.

During September the southwest monsoon gradually weakens, dying out first in northwest India and gradually retreating southward. As the winds cease and the skies clear, the temperature increases somewhat, even though the sun is moving southward. This is generally a warm and dry season during which, however, the air is still humid. The water vapor is supplied in part by evaporation from the wet soil. Northern India is dry and pleasant, the interior of the peninsula has light rain from occasional thunderstorms, and the southeast coast receives heavy rain in places where the winds are still directed inland against the Eastern Ghats. There are also occasional heavy autumn rains in the southeast of India caused by the tropical cyclones from the Bay of Bengal.

The isotherm of 65° for the coldest month, January, crosses India at about latitude 24° N. from the delta of the Ganges to the delta of the Indus, near the border of Baluchistan. The peninsular portion of India, south of this isotherm, has a tropical climate. North of this isotherm temperature conditions are subtropical. A large part of this northern area has a humid subtropical climate (STH), and another large part has steppe and desert conditions. These regions will be discussed later. India as a whole supports an immense population, 75% of which is agricultural. The whole structure of its life therefore is dependent upon the summer monsoon. It raises all its own food, except that it imports some sugar.

Peninsular India

The January mean temperatures in tropical India range from 80° in the extreme south to 65° at the northern border of the region. The months of highest mean temperature are April, May, and June, the hot transition season. The mean temperatures of

the hottest month are 85° to 95°, equalled in the United States only in the southwest desert region. They are highest in the northern interior. The annual temperature range is 10° to 20°, and more at stations above 2,000 feet. The annual rainfall is from thirty-five to seventy-five inches; the least amount is in the interior, in the rain shadow of the Western Ghats.

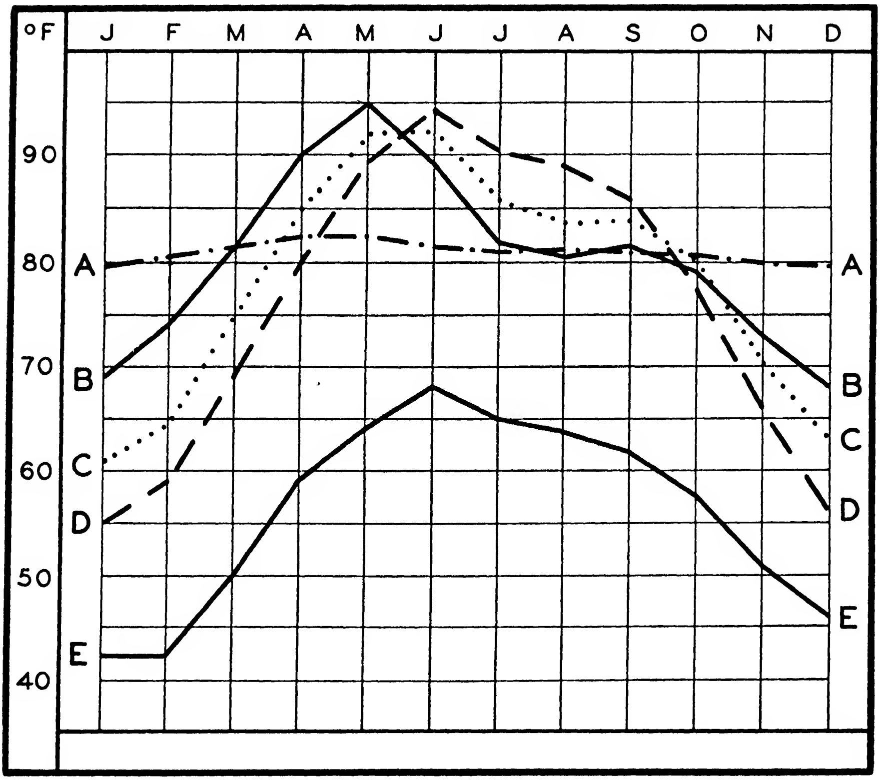

FIG. 79—Average Temperature. Tropical, subtropical, and mountain climates of India.
A. Colombo, Ceylon (TRm). C. Jaipur, northern India (STH).
B. Nagpur, central India (TS). D. Lahore, northern India (STH).
E. Simla, northern India (Mt.).

At Bangalore in the southern interior the yearly total is 35.29 inches; there are amounts of more than three inches each month from May to October, but rather insignificant amounts from December to March—a four-month dry season. At Nagpur in the northern interior the total rises to 46.39 inches. There are 13.34 inches in July and 10.34 inches in August, but less than one inch

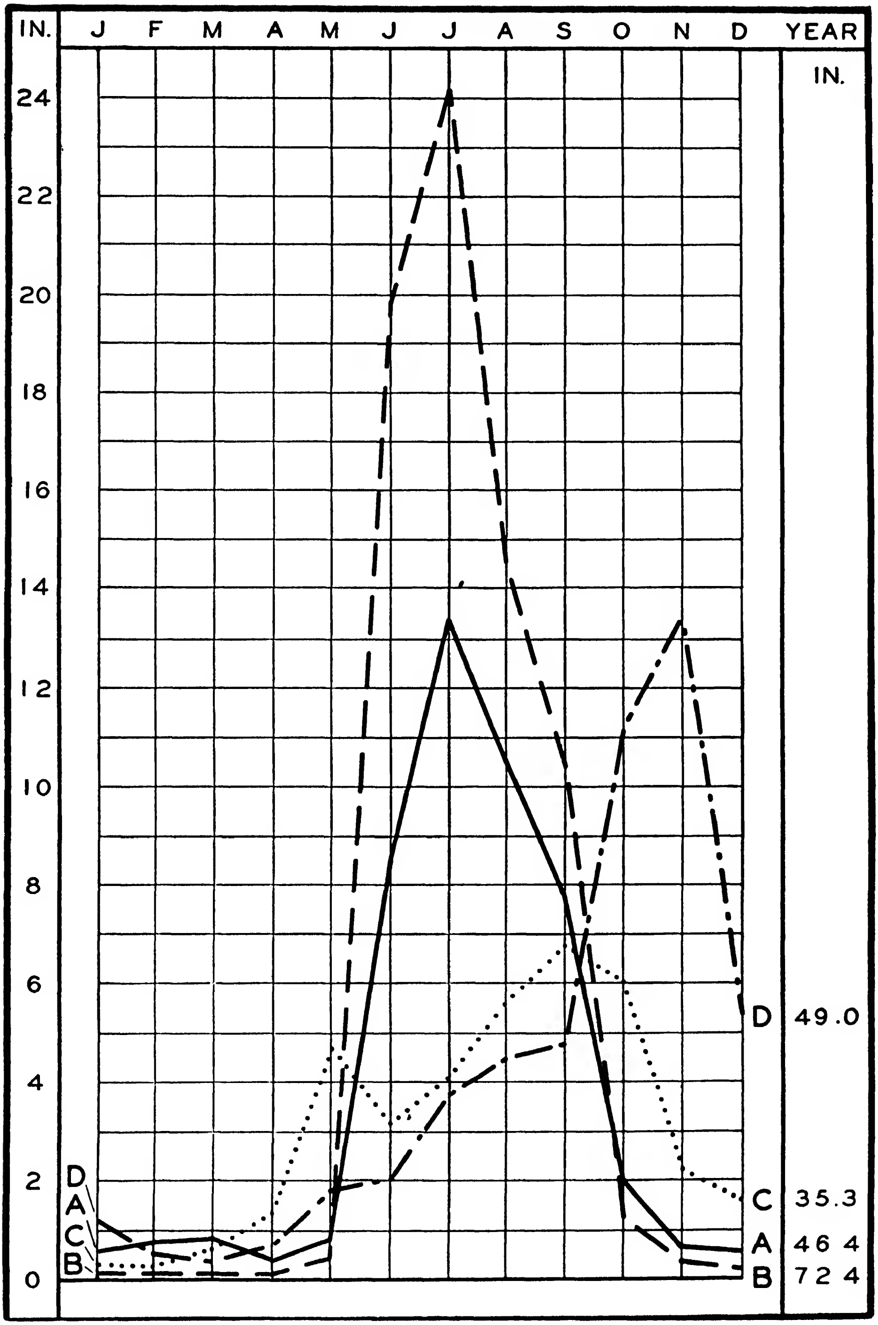

FIG. 80—Average Precipitation. Tropical savanna climate of Peninsular India.
A. Nagpur. B. Bombay. C. Bangalore. D. Madras.

in each of the months from November to May—a short season of excessive rainfall, and a long, dry season of seven months' duration. The southeast coast receives its heaviest rain with southeast winds in the time of the retreating summer monsoon. Madras, for example, has 11.15 inches in October and 13.61 inches in November; half of its annual total thus falls during these two months. But this coastal region receives moderate rain in the regular monsoon rainy season, and has a dry season of only three months, February, March, and April.

The interior of the peninsula known as the *Deccan,* a tableland 2,000 feet high with pronounced wet and dry seasons, is the chief cotton-producing region of India. The hill region of southern India is important in the production of tea and coffee, and the tea is without a dormant season. The east coast, most of which has more rain and a longer rainy season than the interior, is a large producer of rice. All of these regions have large acreages devoted to such crops as sorghums and millets. Rice and sugar are wet crops, and require irrigation; the grains are unirrigated winter crops. Most of the farming is in small tracts intensively cultivated.

The Humid Subtropical Climate of Northern India (STH)

That part of India north of latitude 24° N., including most of Assam in northeast India, the greater part of the Ganges Valley (except the delta), and the Punjab in northwest India, has a climate similar to that of peninsular India just described, except that winter temperatures fall below 64°. It is sometimes included with the rest of India in the tropical savanna climatic province, but the lowland portions have a humid subtropical (STH) climate as defined in Part I, and this merges on the north into the colder climates of the highlands. The monsoon control of the seasons prevails as in southern India, but as has been previously pointed out, the winter monsoon is from the northwest in the Ganges Valley and the summer monsoon from the southeast.

The major rainfall occurs during the summer monsoon, and, except in Assam, there is a long dry season from October to May. In Assam heavy thunderstorms develop during the hot transitional seasons of light, onshore, up-slope winds. Accordingly, this region has a long rainy season. It receives more than eighty inches of rain per year in the lower portions, and more than 100 inches near

the hills. It is in the Khasi Hills of Assam (an outlying range of the Himalayas) that Cherrapunji is situated, which, at an elevation of 4,309 feet, has a mean annual rainfall of 428 inches and vies with Mt. Waialeale, Hawaii, as the wettest rainfall station of

STH *Climate of Northern India*	*Elevation (Feet)*	*Mean Temperature, °F.*				*Av. Precipitation (Inches)*		
		Year	*Coolest month*	*Warmest month*	*Range*	*Year*	*Wettest month*	*Driest month*
Benares	267	77.2	Jan. 60.0	May 91.3	31.3	40.6	July 12 1	Dec. 0.2
Cawnpore	416	77.1	Jan. 58.8	May 92.6	33.8	32.1	Aug. 10.2	Nov. 0.2
Delhi	718	77.1	Jan. 57 9	June 92.2	34.3	26.2	July 7 6	Nov. 0.1
Jaipur	1430	77.1	Jan. 59.9	May 91 6	31.7	24 0	July 8 3	Nov. 0.1
Lahore	700	74.7	Jan. 53 0	June 93.0	40.0	18 1	July 5 1	Nov. 0.1

the world. Cherrapunji has two dry months, December and January. The slopes and basins of Assam are a center of tea production in spite of the fact that the plants have a season of slow growth during the cool months. They grow rapidly in the long, hot, and humid summers.

The Ganges Valley has two or three winter months with mean temperatures below 64°, but with the cessation of the winter monsoon the temperature rises rapidly, and May and June have mean temperatures above 90°. Heavy rain falls in the short rainy season, June to September (especially during July and August). October sometimes has moderate amounts of rain. The other seven months have less than one inch each, and average less than half an inch. The total for the year decreases from eighty inches in the east to twenty inches in the west as the Thar Desert is approached.

The Ganges Valley is the center of sugar production in India, and rice is also extensively grown. Both of these crops require supplemental irrigation during the long dry season. Winter crops of corn and barley are also grown.

The Punjab region in the upper Indus Basin, like the Ganges

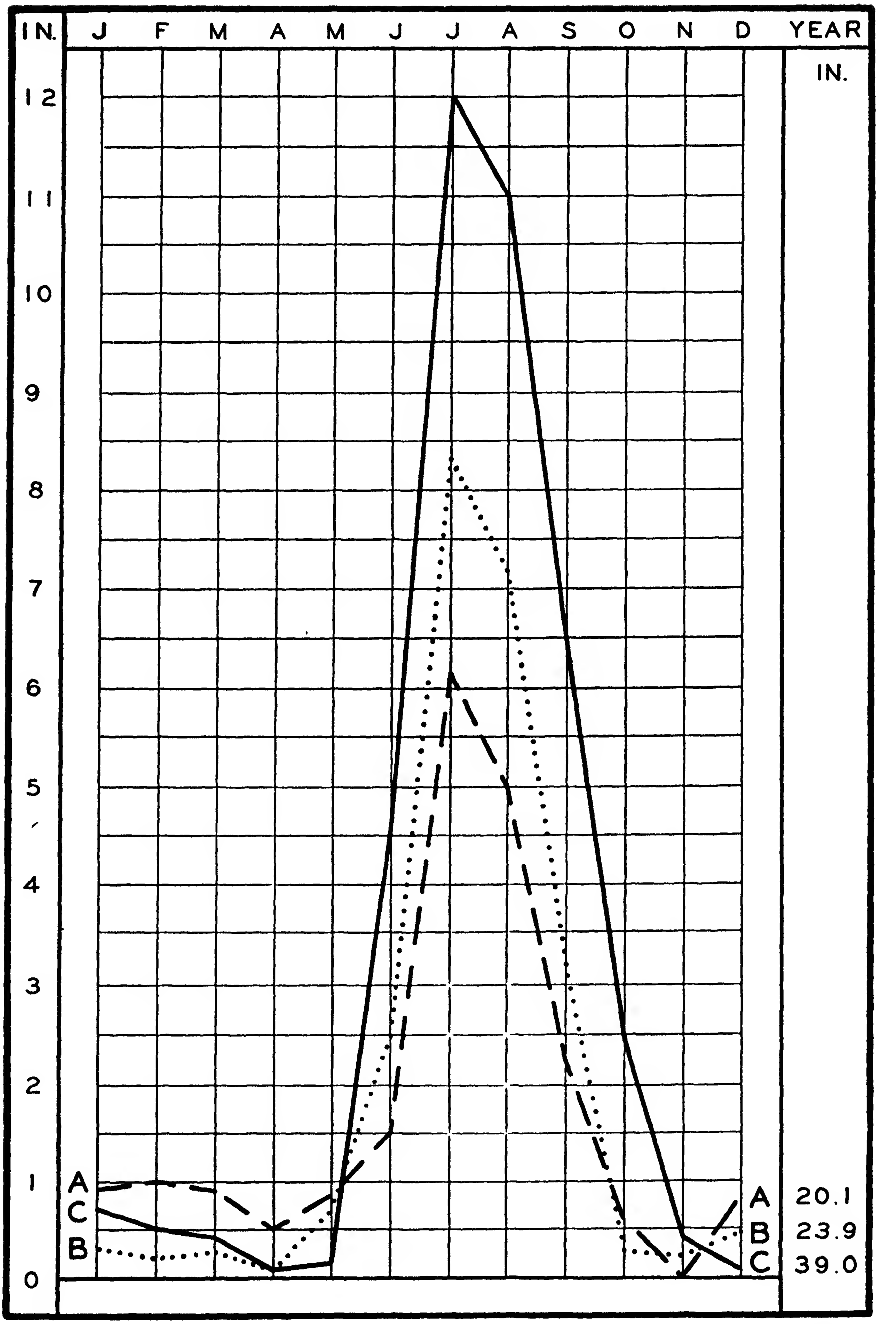

FIG. 81—Average Precipitation. Humid subtropical climate of northern India.
A. Lahore. B. Jaipur. C. Allahabad.

Valley, has three very hot months, May, June, and July, but the winters are somewhat cooler than in the Ganges Valley. December, January, and February are cool, dry, and bracing, and there is occasional frost. The rainy monsoon is late in reaching this northern region and early in quitting it, and the rainfall over much of the area is about twenty inches, of which more than half falls in July and August. With increasing elevation as the mountains are approached, the temperature decreases and the rainfall increases, but irregularly; both temperature and rainfall are much influenced by local conditions of exposure. At Peshawar (elevation 1,113 feet) the January mean temperature is 50°, and the annual rainfall is only sixteen inches. Srinagar, at 5,200 feet, has a January mean of 31° and a rainfall of twenty-six inches, and Simla, at 7,200 feet, has a January and February mean of 42° and a rainfall of eighty inches. These two stations are, therefore, outside the subtropical province. In the Punjab region most crops depend upon irrigation. Some cotton is grown, but a greater acreage is devoted to wheat, sorghums, millet, and other mid-latitude, light-rainfall crops.

The great Himalaya Mountain system and its outlying ranges and foothills present many zones of climate according to elevation and exposure; these zones include subtropical areas, various moderate and cold types, and regions of perpetual snow and ice. The lower mountains are forest-covered and yield much valuable timber, but they are perhaps most valuable to the white inhabitants of India as retreats from the enervating heat of the tropical plains.

CHAPTER XVII

Dry Climates of Eurasia

Because of its openness to marine influences, Europe is without deserts, and the only semiarid region is southern Russia in the vicinity of the Black and Caspian seas, embracing portions of the Ukraine and the northern Caucasus. Asia, on the other hand, has vast areas of steppe and desert, high and low, hot and cold. These areas extend from the Ukraine, Turkey, and Arabia eastward to Mongolia, western China, and western India, and they cover a latitudinal range of 42°, from 13° N. to 55° N. Indeed, almost all of Asia, excluding India, southeastern Asia, and the eastern half of China, has less than twenty inches of rain a year. The northern portions escape being classed as dry climates only because they are so cold that there is little evaporation. Several factors are involved in causing these dry regions. The major ones are the great distance from the sea and the presence of intervening mountain barriers. In the southwest the trade wind latitude and the prevalence of continental winds are important reasons for aridity.

The Steppes and Deserts of Southwest Asia

From the Thar Desert of western India westward across Baluchistan, Afghanistan, Iran, Iraq, Arabia, and on into Africa is an immense and almost continuous desert and steppe area. It is dry in spite of the fact that much of it is adjacent to warm water surfaces. The factors associated with its aridity are: (1) the latitude—it is in the subtropical high pressure belt of subsiding air, and (2) the pressure distribution—this gives cold, dry, northeast winds from interior Asia in winter, and west or northwest winds on the western side of the Asiatic low in summer; the latter winds move across large land areas and from cooler to warmer regions, and are therefore dry.

In general, the summer climate of southwest Asia is simple and uniform, and there are no storms or daily changes. In the interior the heat is intense by day, but the air is dry and almost cloudless,

and the cooling by night is considerable. The surface heating by day results in fresh to strong afternoon winds which often carry clouds of dust and sand. On the coast, regular sea breezes temper the daytime heat, but increase the humidity. In winter, conditions are much more changeable. Invasions of polar continental air from the high pressure regions of central Asia alternate with warm humid air masses from the Arabian Sea in front of traveling cyclones moving eastward from the Mediterranean region. Thunderstorms sometimes occur where these differing air masses meet—especially in the higher regions where orographic uplift aids in the process of condensation.

The Thar Desert and the Indus Valley

The alluvial plains of the Indus River and the sandy plains to the east of it are desert regions (STD) of high temperature and scant and uncertain rainfall. Bordering the desert on the east is a narrow steppe region, forming a transitional zone between the desert and the humid subtropical province of northwest India. In the interior of the desert, mean summer temperatures rise to 95°, as in Arabia and the Sahara, and maximum temperatures reach 120°. On the other hand, the winter average is about 60°, and freezing temperatures occasionally occur at night. The yearly rainfall varies from two or three inches to eight or ten inches. Sometimes two or three years will pass without a drop of rain, and then an entire year's normal rainfall will occur in a few days. The reasons for the great aridity are: (1) the prevailing winds during the cooler months are the northeast monsoons, which are normally dry and which are made drier by their crossing of the Himalayas and their descent into the Indus region; and (2) in the summer season the cyclonic circulation on the west of the interior center of low pressure results in dry and descending air from the west and northwest instead of the moist air of the southwest monsoons. There are no rain-bearing winds at any season.

The Indus River receives abundant water from the Himalayas, and the valley depends on the river for its life, much as Egypt depends upon the Nile. Temperature conditions are, in the main, subtropical, and under irrigation rice, cotton, indigo, and cereals are produced.

The Iranian Plateau

Extending westward from the Indus Valley to the valley of the Tigris is an irregular, rugged upland region known as the *Iranian Plateau* and comprising the political subdivisions of Afghanistan, Baluchistan, and Iran (Persia). The region is mostly 4,000 to 8,000 feet in elevation, but there are narrow lowland areas along the Persian Gulf and along the southern portion of the Caspian Sea. The climate is largely continental rather than marine because the prevailing winds are from land surfaces at all seasons. In the winter strong northeast monsoons prevail; in the summer winds are from the west or northwest because of the general pressure gradient between the Azores high and the low of interior Asia. For this reason the region is arid or semiarid, except in some mountain areas. For the same reason, and also because of its elevation, it is rather cold for its latitude. The northern half may be called *middle latitude steppe and desert,* and only the south half is classed with the low latitude dry climates.

Iran (Persia)

Iran contains a large central desert plateau 4,000 feet or more in elevation which is surrounded by irregular mountain ranges which rise to 8,000 feet. The desert extends from the southern slope of the Elburz Mountains, near the Caspian Sea, southeastward to latitude 30° N. It is 800 miles long, and from 100 to 400 miles wide. The rest of Iran consists of detached mountain ranges and intermontane valleys of steppe character.

In the desert region the rainfall is five to eleven inches a year, and in the rest of the area about ten to fourteen inches, but it rises above fourteen inches along the Caspian Sea and in extreme northwest Persia west of the Caspian Sea. The summers are practically rainless, most of the rainfall occurring in the winter months from November to March. A considerable portion of the precipitation is snow, especially in the northern region and in the mountains. Thus is the flow of streams during the dry season maintained and water for irrigation furnished. This winter precipitation is largely cold front precipitation, occurring with north or northwest winds on the western side of barometric depressions that move inland from the Mediterranean region. These traveling lows, preceded by warm, moist air, are often followed by cold

waves attended by temperatures as low as 20° in some northern areas. Frosts occur in almost all regions, except in the southern coastal lowlands. Native vegetation is of steppe character and generally scanty. Wheat, barley, peas, and beans are grown in all cultivated districts, and rice wherever water is available. Under irrigation quinces, peaches, apricots, figs, and other fruits are grown in southern Iran and in the Caspian lowlands.

Afghanistan and Baluchistan

These countries form the eastern portion of the Iranian plateau and, like Persia, they consist of desert plateaus and rugged, hilly, steppe regions. The desert plateaus are confined to southwestern Afghanistan and northwestern Baluchistan, adjoining the Iranian desert, but desert conditions continuous with those of the Indus Valley extend into eastern and southern Baluchistan. The climate varies greatly—from cold continental in northern Afghanistan to subtropical in southern Baluchistan—and there is an immense variety of local climates, depending on elevation, slope, and trend of mountains. There are sudden changes of temperature as tropical air is replaced by cold continental air, and there are large, daily ranges of temperature which are due to rapid radiation in the elevated dry air.

Afghanistan has an average annual temperature of 50° to 60°, but temperatures fall to — 10° or lower occasionally during the winter months, and rigorous winter conditions prevail for two or three months. On the other hand, the summer heat is great everywhere and maximum temperatures rise to 110°, sometimes attended by hot winds and dust storms. In short, Afghanistan has a typical continental steppe or desert climate, with low humidity and a high percentage of sunshine. Most of the light rainfall occurs in winter and spring in connection with traveling lows, but in the eastern portion where the slope is toward India, the summer monsoon that moves up the Ganges Valley brings some rain. The climate of the northern half of Baluchistan is much the same as that of Afghanistan. In the southern half the winters are milder, with fewer cold waves, and the maximum rainfall is in summer. At Karachi on the Arabian Sea the annual rainfall is 7.41 inches. Agriculture is largely dependent on irrigation provided by the melting snows of the mountains. Wheat, barley, and lentils are

harvested in the early summer; rice, tobacco, and sorghums are harvested in the autumn. The arid plains and rugged highlands furnish pasturage for sheep and camels.

Turkey, Syria, and Iraq

Another highland area extends westward from the Iranian Plateau, and includes the northern portions of Iraq and Syria and all of Asiatic Turkey except the narrow coastal plains along the Black, Aegean, and Mediterranean seas. (These coastal lowlands have a Mediterranean climate which will be described later.) These highlands are 3,000 to 6,000 feet in elevation, and the climate, marked by long, cold winters and short, dry summers, is continental in character. The daily range is high, as is characteristic of plateaus. Winter winds are prevailingly from the northeast, around the secondary center of low pressure over the Mediterranean. Summer winds are from the north or northwest under the general control of the Asiatic low and the Azores high. Thus there is dry continental air at all seasons, and the rainfall is scanty. Most of the rain falls in winter in connection with traveling depressions moving eastward from the Mediterranean. On the cold front in the rear of these depressions the rain turns to snow, which is sometimes followed by a cold wave and zero temperatures. In summer and autumn the northerly winds are uninterrupted by cyclonic storms, and these seasons are continuously hot, dry, and almost rainless. Vegetation becomes brown and parched, the plains are deep in dust, dust storms are frequent, and the sky is milky white, but cloudless.

The central plateau of Turkey is a highland steppe region of grassy hills and plains with some arable valleys. Wheat and other cereals are the chief agricultural products. Tobacco is grown throughout the plateau, and cotton in some areas. Grasslands support large numbers of sheep and angora goats. There are small desert areas where the rainfall is less than eight inches a year. Annual amounts increase to fifteen inches in much of the plains area, and to over twenty inches on the windward slopes of the mountain ranges. At Sivas in central Turkey, at an elevation of 4,400 feet, it is seventeen inches; at Angora it is ten inches. Sivas has a July mean temperature of 67°, a January mean of 21°, and an absolute minimum of —20°.

Steppes and Deserts of Southwest Asia	*Elevation (Feet)*	*Mean Temperature, °F.*				*Av. Precipitation (Inches)*		
		Year	*Coolest month*	*Warmest month*	*Range*	*Year*	*Wettest month*	*Driest month*
Indus Valley								
Peshawar	1113	71.4	Jan. 49.7	June 91.2	41.5	15.9	Aug. 3.3	Oct. 0.3
Multan	420	77 5	Jan. 55 6	June 94 9	39.3	6 8	July 1 9	Nov. 0.1
Karachi	13	77 6	Jan. 65.3	June 86 8	21.5	7 6	July 2 9	Oct. 0.0
Iranian Plateau								
Teheran	4002	61 7	Jan. 33 6	July 84.9	51.3	9 53	March 1 96	Aug. 0.04
Meshed	. . .	56 2	Jan. 34 4	July 76 5	42 1	9 22	March 2 24	Sept. 0.02
Ispahan	. . .	. .	. . .		.	4 49	Dec. 0 87	Aug. 0.01
Bushire		75 2	Jan. 57 9	Aug. 90 2	32 3	10 39	Dec. 2 94	June to Sept. 0.0
Jask	13	79 9	Jan. 67 4	July 90 7	23 3	4 51	Jan. 1.13	July–Sept. 0.0
Quetta	5500	58 1	Jan. 39.6	July 77.8	38.2	10 0	Feb. 2 1	Oct. 0.1
Turkey—N. Iraq								
Sivas	4200			. .		16 90	Jan. 2 10	Aug. 0.10
Mosul	870	66 8	Jan. 40 2	July 90 5	50.3	16.70	Feb. 2 90	June–Sept. 0.0
Lower Tigris and Euphrates								
Baghdad	220	73.0	Jan. 48 9	July 94 4	45 5	7 08	March 1 34	June–July 0.0
Basra	26	74.9	Jan. 52 1	July 93 0	40 9	6.42	Jan. 1 37	June–Aug. 0.0
Arabia								
Aden	94	82.9	Jan. 76.3	June 89.4	13.1	1.84	March 0.48	July 0.03
Muscat		. . .	. . . .	. . . .	. . .	4.19	Jan. 1 16	Sept. 0.00

Upper Syria and Iraq receive more warm, moist air from the Persian Gulf in the warm sector of moving lows, and the winters are milder than in Turkey. At Mosul, north Iraq, the January mean temperature is 40°, and the lowest of record is zero; at Baghdad the January mean is 49°, and the absolute minimum is 10°. The summers are rainless, cloudless, and intensely hot. The July mean at Baghdad is 94°, and the absolute maximum is 123°. Maxima above 100° occur almost every day during July and August, but low humidity and good air movement make the sensible temperature moderate. In southern Syria and southwestern Iraq conditions approach the desert conditions of northern Arabia, and in places the annual rainfall is less than two inches.

The Valleys of the lower Tigris and Euphrates

This region was the center of an ancient civilization and of an elaborate irrigation system. It is now mostly an arid forsaken plain of brush and weeds and tamarisk jungles, its intricate irrigation system in ruins and its rich alluvial soil untilled. But the climate remains unchanged, and the Tigris and Euphrates continue to rise and overflow their banks in spring and to furnish ample water for irrigation. In climatic characteristics the region is a low latitude desert (STD) of subtropical temperatures, high evaporation, and less than ten inches of rain. The rain falls in the winter; the summer landscape is scorched, and, without irrigation, almost lifeless. At Basra the July mean temperature is 93°, and the coldest month is January, which has a mean of 53°, permitting continuous winter growth. The small percentage of the area that is under cultivation furnishes a very large part of the world's supply of dates. Other crops produced are citrus fruits, cotton, rice, and tobacco.

Arabia

Along the southern half of the Arabian coast of the Red Sea there is a narrow, coastal plain, not over thirty miles wide, from which a chain of mountains rises sharply to heights of 4,000 to 8,000 feet. Above 5,000 feet this highland region has considerable rainfall from the southwest monsoon and moderate temperatures, giving it a warm, semiarid to moderately moist climate (STS). Rain on the higher mountains furnishes water for irrigating the

upland valleys. This is the most favored climatic and agricultural region of Arabia, and it produces grapes, apricots, peaches, figs, and bananas (warm subtropical products). The famous Arabian coffee is an important crop on the western slopes at elevations of 4,000 to 7,000 feet. In southeast Arabia a narrow highland strip near the Gulf of Oman has a somewhat similar, but warmer and drier, steppe climate.

The coastal strips are hot, moist, and oppressive, with mean maximum temperatures of 95° to 98° and with minima of 67° to 70°; the annual ranges are small, and there is less than five inches of rainfall a year. (See Aden and Muscat.) The remainder of Arabia is a hot and barren desert plateau (STD) sloping gently from southwest to northeast, with an average elevation of about 3,000 feet. Mid-summer daily mean temperatures are about 95° in spite of a large daily range due to rapid cooling after sunset. In the cooler months, this rapid radiational cooling results in frequent frosts and freezing temperatures at night in the higher, western portion of the peninsula. Precipitation is scanty and irregular, mostly in the winter months, and is in the form of scattered showers. A given locality may be entirely without rain for two or three years, and then may receive scattered heavy showers because the cold front of a Mediterranean low has dipped unusually far southward.

The northern third of this interior plateau is a sandy or stony desert which receives enough rain to produce some winter pasturage, and which, in consequence, supports a small pastoral, nomadic population. The central third has irregular mountain chains that intercept some moisture and give rise to intermittent streams. The alluvial valleys traversed by the wadies support a considerable settled population. The principal agricultural plant is the date palm. The southern third of this plateau is an empty, uninhabitable desert, without vegetation and evidently almost without rainfall. It is in the rain shadow of the western mountains, which are highest in the south.

The Middle Latitude Steppes and Deserts of Central Eurasia

A great arid and semiarid region reaches across southeastern Europe and central Asia from the Black Sea to Manchukuo (Manchuria). It extends northward beyond latitude 50° N. and south-

ward to the Caucasus, the steppes of Afghanistan, and the highlands of inner Asia. In the main it is a vast, high plain bordered on the south by lofty plateaus and great mountain systems, but in this plain there are depressions in which the elevation approaches sea level. Because of the mountain barriers and the great land masses on all sides, continental winds prevail at all seasons. In the winter the winds are controlled by the high pressure centered over Mongolia and the Lake Baikal region, and are northerly and easterly. In the summer the winds are from the north or northwest in the western portion and from the south in the eastern portion. These latter are the southerly monsoons, but they lose their moisture in China and Manchuria and reach the interior dry and weak. Hence there are no dependable rain-bearing winds at any season.

Except for a small transition zone on the north and east of the Black Sea, where the climate approaches the Mediterranean type, the climate is continental, with hot summers, cold winters, and light to scanty rainfall, mostly in summer. There are three great deserts within the region: the Aral-Caspian depression, the Takla-makan of Chinese Turkestan (Sinkiang), and the Gobi Desert of Mongolia. These are surrounded by extensive middle latitude steppe regions.

Ukraine

The Ukrainian Region from the Black Sea northward to about latitude 51° N. is a fertile, undulating plain covered with a thick layer of black earth, and is treeless except for woods and thickets in the ravines and near the rivers. The climatic type is middle latitude steppe (IS). West of the Dnieper River the rainfall is fifteen to twenty inches a year, two-thirds of which falls in the growing season, and here there are prairies with extensive fields of wheat, barley, flax, and sunflowers. East of the Dnieper drier conditions prevail, and the annual rainfall averages ten to fifteen inches. Here the plains are richly covered with grasses in spring, but, with the exception of the yellowish steppe-grass, these disappear in the heat of summer. The summers are short and hot and the winters cold. At Odessa on the Black Sea the yearly rainfall is 15.6 inches, the mean annual temperature 49°, the January mean 25°, and the July mean 72°. These temperature values are

about the same as for Detroit, but the rainfall is more like that at Bismarck. As one goes northward from the Black Sea, the winters get rapidly colder and the summers somewhat warmer.

Caucasia

The region of the Caucasus lies between the Black Sea and the Caspian Sea. In its southern portion a system of highlands connects the two seas, and in these highlands there are places of heavy rainfall. Particularly on the east coast of the Black Sea, where westerly winds blow against the mountains, the rain amounts to sixty-five to eighty inches a year in certain locations, and these areas are therefore to be distinguished from the steppe regions. North of the highlands the steppe lands are similar in character to the Ukraine, and they extend westward to join the Ukrainian steppe. At Stalingrad on the Volga the annual mean temperature is 44°, ranging from 13° in January to 75° in July. These values are near those for Minneapolis, except that July is more than 1° hotter at Stalingrad. At the northern end of the Caspian Sea the steppe changes into desert, and in the Astrakhan region at the mouth of the Volga the rainfall is less than five inches a year, and the black earth is replaced by sand and saline clays.

Russian Turkestan

The desert that begins in the basin of the lower Volga River extends around the northern end of the Caspian Sea and along its entire eastern boundary and then eastward to Lake Balkhash and the western slopes of the Tien Shan ranges. This great desert is bounded on the north, entirely across northern Turkestan, by a large semiarid region known as the *Kirghiz Steppes.* The desert is an immense lowland plain, sometimes called the *Caspian Depression,* not over 400 feet high, and in places even below sea level. The fact that this plain is lower than its surroundings is one reason for its being a desert; any air that reaches the plain from other regions is descending air. It is a cold and barren desert, wholly destitute of vegetation, with temperatures falling below zero in winter and rising above 100° in summer. Some snow falls in winter, but it is blown into drifts by the frequent high winds called *burans,* which correspond to the blizzards of the American Great

Plains. In the summer the heart of the desert area is almost rainless and cloudless, but scattered showers may occur at long intervals.

Russian Turkestan is bounded on the east by the Tien Shan (*Shan* signifies mountain chain) which rises rather abruptly to elevations of 10,000 to 20,000 feet and which intercepts much moisture. These highlands are fringed at their base by plains ranging from 7,000 down to 1,000 feet in elevation. Favorable slopes in the higher plains receive ample moisture to produce forests, and also have areas of rich meadow and orchards of apples and apricots. The lower plains have ten to twenty inches a year, and constitute a prairie belt producing wheat and rye. There are also many small irrigated patches and oases along the edge of the desert in southern Turkestan, as at Taskkent and Samarkand. Some of the sheltered valleys with good air drainage have surprisingly mild winters and long growing seasons, and produce such crops as cotton, grapes, almonds, pomegranates, and figs. In most locations winter temperatures are too low for these crops, and the cultivated land is devoted mainly to wheat, barley, millet, melons, and vegetables. Somewhat more than half of the area of Russian Turkestan is desert, about two per cent is arable, and the remainder is pasture land. The pastures are especially in the Kirghiz Steppes of the northern portion, and support large flocks of sheep.

Most of the streams that issue from the mountains are soon lost in the desert, "where the summer floods o'erflow when the sun melts the snows in high Pamir," but two streams, the Syr Darya and the Amu Darya or Oxus do cross the desert to the Aral Sea. Of the course of the Oxus through the desert Arnold wrote:

> ". . . The majestic river floated on,
> Brimming and bright and large; then sands begin
> To hem his watery march, and dam his streams,
> And split his currents; that for many a league
> The shorn and parcelled Oxus strains along
> Through beds of sand and matted rushy isles—
> Oxus, forgetting the bright speed he had
> In his high mountain cradle in Pamir,
> A foiled, circuitous wanderer—till at last
> The longed for dash of waves is heard, and wide
> His luminous home of waters opens bright
> And tranquil."

Sinkiang and Mongolia

Deep in the interior of Asia there is an immense enclosed plateau over 2,000 miles long and 300 to 800 miles wide which forms a great desert and steppe region very imperfectly known. On the west it is bounded by the Pamirs, on the northwest and north by the Tien Shan, and by numerous ranges extending northeastward to the Lake Baikal region. On the southwest are the Kunlun Mountains separating it from the even higher plateau of Tibet, and on the east and southeast are numerous broken and somewhat lower ranges that form the boundary between the desert region and Manchuria and China proper. Although the greater part of this tract is 3,000 feet or more above the sea, there are basins and depressions in it that descend to near or below sea level. Its position in the heart of the largest land mass on the globe and the fact that it is surrounded by higher land are two factors that make it naturally a region of deficient rainfall. Again, its interior position and its latitude, mostly between 40° N. and 50° N., result in continental temperature conditions.

The western portion of this region is Sinkiang, or Chinese Turkestan. The southern part of Sinkiang is largely occupied by the desert of Taklamakan. From this region desert conditions continue eastward, and the Taklamakan connects with the Gobi Desert of Mongolia. Large parts of both are pure deserts of drifting sand, forming dunes thirty to 300 feet in height which move 150 feet a year. These desert areas probably have an average annual precipitation of about two inches, part in the form of winter snows and part in the form of heavy summer showers at long intervals.

The summers are intensely hot and dry, and the winters are cold, dry, and quiet. At Lukchun in a depression in eastern Sinkiang, at an elevation of 100 feet below sea level, a short record indicates that the annual mean temperature is 56°, with a January mean of 13° and a July mean of 90°—as cold as Minneapolis in winter and as hot as Phoenix in summer. The extremes recorded are —5° and 118°. A minimum of —26° has been recorded in the Taklamakan. In the highlands on the northern border of the Gobi Desert, Urga and Ulasutai have January mean temperatures of —12° to —15°. The annual ranges of temperature in these deserts and the surrounding highlands are extreme—more than 70°—and the rapid rise in temperature during the spring months

is notable; March is about 20° warmer than February, and April is 20° warmer than March.

Steppes and Deserts of Central Eurasia (with some humid localities)	*Elevation (Feet)*	*Mean Temperature, °F.*				*Av. Precipitation (Inches)*		
		Year	*Coolest month*	*Warmest month*	*Range*	*Year*	*Wettest month*	*Driest month*
Ukraine								
Kiev	590	44 4	Jan. 21.2	July 66.7	45.5	23.6	July 3.2	Feb. 1.2
Odessa	210	49 9	Jan. 26.4	July 72.7	46.3	15.4	June 2 2	Feb. 0.9
Caucasia								
Astrakhan	−50	48.6	Jan. 19.2	July 76.1	56.9	5.9	June 0.7	Feb. 0.3
Batum	20	57.8	Jan. 43 3	Aug. 73.6	30.3	93.3	Nov. 12.2	May 2.8
Tiflis	1350	54 6	Jan. 32.2	Aug. 76.3	44 1	19.8	May 3.4	Jan. 0.6
Baku	0	57.0	Jan. 38.1	Aug. 77.5	39.4	9.5	Jan. 1.3	July 0.2
Russian Turkestan								
Krasnovodsk	−66	....	.....	....	....	6.3	April 1.0	July 0.2
Merv	755	. ..	....	....	....	7.5	March 2.1	June–Sept. 0.0
Tashkent	1610	55.8	Jan. 29 7	July 80.2	50.5	14.6	March 2.6	Aug. 0.1
Sinkiang								
Kashgar	4255	54.6	Jan. 21.8	July 79.7	57 9	4.0	May 1.0	Aug. Oct. Nov. 0 0
Lukchun	−50	56.0	Jan. 13.2	July 90.5	77.3	. ..	. .	. . .
Mongolia								
Ulasutai	5365	32.0	Jan. −12.0	July 66.0	78.0	....	.....	.
Urga	3800	27.7	Jan. −15.2	July 63.5	78.7	9.5	.....	....

In winter there is little wind because the great high pressure area is centered over the region. Because of the breaking up of this high pressure in spring, the development of the summer low

in the southwest, and the intense heating of the surface by day, strong east to northeast winds develop during the day in spring and summer. These produce the drifting sand dunes and fill the air with dust and sometimes, in the spring, with driving snow. The settling of this dust on the plains at the foot of the mountains builds up a deep loess soil. The winds die down after sunset and the nights are clear and quiet.

On the western border of Taklamakan and on the southern border of both the Taklamakan and the Gobi deserts, there are strips of higher plains, fifty to seventy-five miles in width, which receive five to twenty inches of rain a year. Some of these places also receive underground water by seepage from the mountains, and in other places water is available for irrigation. These favored localities produce grains, cotton, tobacco, rice, fruits, grapes, and melons. At Kashgar and Yarkand in extreme western Sinkiang, at elevations of about 4,200 feet, the mean temperature is approximately like that of Missouri, but the winters are as cold as those in Des Moines, and the summers are as hot as those in Montgomery, and subject to a much greater daily range; it is hotter by day and cooler by night. At these stations the rainfall is only four to five inches a year and falls mostly during March, April, and May—the transition period between winter and summer conditions.

The northern portions of Sinkiang and Outer Mongolia consist of rough and hilly high plains 3,000 to 5,000 feet above sea level. Rainfall is very unevenly distributed, depending on slope and exposure. It is generally light, but in some places, especially on slopes that face north or east, it is sufficient to produce much pasturage for sheep, cattle, horses, and camels. Stock raising is the chief occupation. Most of the rainfall is in summer with easterly winds. These are the summer monsoons, which, however, are rather weak and dry by the time they have penetrated so far inland. The winters are severe and the summers cool. Blizzards are frequent in spring.

Tibet

Tibet, isolated by high mountains on all sides, is the most extensive plateau of great height in the world. Although its climate is essentially a mountain climate—that is, a series of many climates varying with elevation and exposure, and having great ex-

tremes and great differences in short distances—brief mention should be made of Tibet here in connection with the high, dry plains of central Asia which have just been described. Its climatic types vary from tundra (PT) to a type that lies between cold humid continental (ICc) and warm humid continental (ICw). Everywhere, because of the great elevation, there are large daily ranges of temperature and great differences between the temperature of objects in the sun and objects in the shade. The northern and western portion, which is a tundra more than 15,000 feet above the sea, consists of valleys and intervening mountain ranges. It has a dry and inhospitable climate, and there are frosts throughout the year. The warmest month probably has a mean temperature of not more than 40°. There are no trees or shrubs, but much of the region has a cover of short grass. South and east of the tundra, at elevations of 13,000 to 15,000 feet, is an upland pasture region of somewhat less severe conditions that supports a scattered nomadic population tending sheep, goats, and yaks. In both of these regions the summers are almost rainless, but there is light snow in winter.

The only agricultural portion of Tibet is the southeastern portion at elevations of 9,000 to 13,000 feet. When the southwest summer monsoons are well-developed, they extend into this area, giving it a short, warm, and rainy season. At places the rain is heavy from May to September, with maximum in July and August at the height of the monsoon. There is a frostless period of about ninety days from the latter half of June to the first half of September, coinciding with the wet season. The period from October to April has dry continental winds and is practically without precipitation; hence snowfall is negligible. Owing to the variability of the monsoons—some years well-developed, other years weak and not reaching Tibet—the rainfall is extremely variable, and the region suffers from both floods and droughts. A short record of four years at Lhasa, the capital of Tibet, at an elevation of 12,244 feet in the latitude of New Orleans (30° N.), shows the following mean monthly and annual values of temperature and precipitation.[1]

[1] From Alfred Lu, "Brief Summary of the Climate of Lhasa," *Quarterly Journal of the Royal Meteorological Society*, Vol. 65, No. 281 (July, 1939), pp. 297–302.

Note that there are five months with mean temperatures above 50°, but none below 32°. (Columbus, Ohio, has seven months above 50° and two below 32°.) Lhasa has a potential growing season of good length for hardy plants—about 140 days. It should be noted also that the heavy rains of July and August keep the temperatures of those months somewhat lower than those of June

	Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	
Temperature, °F.	32	34	43	49	56	63	
Precipitation (Inches)	T	.06	.34	.16	5.14	6.27	
	July	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*
Temperature, °F.	61	60	59	48	40	33	48 (Av.)
Precipitation (Inches)	25.82	17.73	7.17	.26	T	T	62.95 (Total)

in spite of the general tendency in elevated regions toward a retardation of the annual maximum. The heavy concentration of the rainfall in July and August gives those two months 69% of the annual total. Most of this rain falls in heavy thundershowers, and results in flooding and much erosion. The excessive variability of the rainfall is indicated by the record of 80.69 inches in July, 1936, and a total of 198.25 inches in that year; the total for the following year, 1937, was only 14.70 inches. Because of this enormous variability, an unusually long record will be necessary to establish stable normal values.

CHAPTER XVIII

Humid Climates of China, Japan, and Manchuria

The position of China in the southeast portion of a continent is similar to that of the eastern half of the United States, except that China (including Manchuria) has a greater latitudinal extent. China has a much larger area south of latitude 30° N., and a portion of Manchuria is north of latitude 50° N. The east-west extent of China proper is through about 23° of longitude, corresponding to the United States from the Atlantic seaboard westward to the eastern portions of the Dakotas, Nebraska, Kansas, Oklahoma, and Texas. Manchuria extends from the latitude of southern Pennsylvania northward to the latitude of southern Labrador. We are thus dealing with an extensive area—a region of great rivers, river basins, hills, valleys, and plains—which is more diversified than the corresponding region in North America.

The position of the island kingdom of Japan is unique in that no other long chain of islands lies off the east coast of a continent. From southern Formosa to the northern Kuril Islands is a latitudinal distance of 28°, corresponding to the distance from Cuba to northern Newfoundland. The main islands of the group occupy a latitudinal range corresponding to that from Jacksonville to Halifax. These islands have narrow coastal plains, and central highlands of irregular, diversified topography. General climatic conditions resemble those of the adjacent mainland.

The climates of China, Manchuria, and Japan are of the same four types found in the eastern United States, but there are important differences in detail. The differences arise in part from the differences between the continents of North America and Eurasia in size, configuration, and elevation. The dissimilarities are indicated in a general way by the statement that the climates of China, Manchuria, and Japan are monsoonal variations of the

climatic types found in eastern United States. As has been previously pointed out, the monsoons are well-developed in eastern Asia. There are strong outflowing winds in winter from the great center of high pressure in the vicinity of Lake Baikal, and somewhat weaker inflowing winds in summer around the interior center of low pressure. Siberia in winter is by far the coldest portion of the world for its latitude, and persistent winds blowing out of this cold area across China make the Chinese winters too the coldest observed in corresponding latitudes.

The winter monsoons, which are from the northwest in northern areas, become north winds at about latitude 30° N. and northeast or east winds south of the Tropic of Cancer. This is in accordance with the normal anticyclonic circulation around the center of high pressure. The summer monsoons are somewhat less reliable than the winter winds. In accordance with the normal cyclonic circulation, they are from the southwest in the extreme southern part of the region, from the south in central China, and from the southeast in Japan, Manchuria, and northern China. With a few local exceptions which will be noted later, rainfall is strongly concentrated in the summer months, when there is a constant supply of moist, tropical maritime air, and it is light, although not completely absent, during the season when cold continental winds prevail. In some years the summer monsoons are strong and persistent, and in other years they are weak and intermittent. Hence there are seasons of excessive rainfall and floods and other seasons of drought and famine. The monsoon rains begin first in the south and gradually progress northward as the season advances. Rainfall, humidity, and cloudiness decrease from south to north and also from the coast toward the interior.

Although Japan is subject to much continental influence in winter because it is crossed by the strong northerly monsoon, its island character also renders it subject to marine influences. Its temperature and moisture are considerably modified by two important ocean currents. A portion of the warm Kuro-shio (Japanese Current) enters the Sea of Japan and flows northward along the west coast of the islands. It helps to increase the temperature and humidity of the winter winds. The main portion of the current flows northeastward east of Japan and influences summer temperatures and humidities, for it is then that the air moves

inland from the eastern side of the islands. In winter there is also a cold current from the north (Okhotsk Current), and a portion of this current cools the east coast of Japan southward to latitude 35° N. Another portion of this current follows the east coast of the continent southward to Chosen (Korea).

The Humid Subtropical Climate of China and Japan (STH)

The southern coastal provinces of China and the island of Formosa (Taiwan) are essentially tropical in some of their characteristics, but the steady winter monsoons prevent much warming by day and occasionally bring near-freezing temperatures at night.

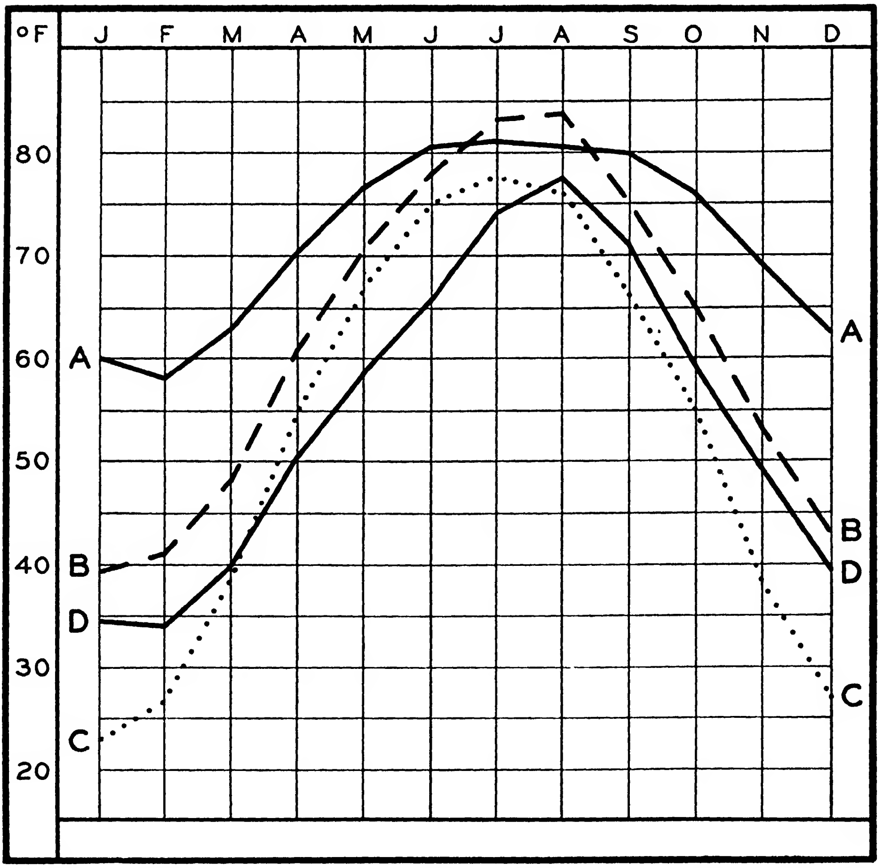

FIG. 82—Average Temperature. Subtropical and intermediate climates of China and Japan.

A. Hong Kong, China (STH).
B. Hankow, China (ICw).
C. Peiping, China (ICw).
D. Niigata, Japan (ICm).

They thus keep the mean temperature of the winter months somewhat below 65°. For this reason this area is classed as subtropical rather than tropical, although a large portion of it is south of the Tropic of Cancer and is in the same latitude as are Cuba and Hawaii, which are fully tropical.

Northward from this near-tropical region, subtropical conditions, limited by the isotherm of 43° for the coldest month, prevail to about latitude 30° (to the Yangtse River) in eastern China, and to somewhat farther north in the interior province of Szechwan, which is in a basin well protected on the west, north, and east by mountain ranges. This climatic type (STII) does not, however, extend as far poleward in China as it does in the United States, South America, or Australia. In the larger Japanese islands subtropical conditions prevail only in a narrow band along the southeast coast between latitudes 30° and 35° N.

China

In the southern coastal region of China and in Formosa there are but two seasons, the hot wet season of the southwest monsoon and the cool dry season of the northeast monsoon. There are four months, December, January, February, and March, when temperatures average below 65°. February, with a mean of 57° in northern Formosa (Taihoku) and 59° at Hong Kong, is the coolest month (see table). An absolute minimum of 32° has been recorded at both of these stations, but in an average year the minimum is above 40°. In summer there are three or four months with mean temperatures of about 80° to 82°, but maximum temperatures are comparatively low. In an average year the highest temperature experienced at Hong Kong is 92° and at Taihoku, 97°.

The rainfall is heavy throughout this region, averaging about 100 inches a year on the south coast and decreasing somewhat inland. More than half of the total falls in the four months of May, June, July, and August, at the height of the summer monsoon, but the rainfall is heavy from April to October inclusive. June is usually the wettest month.

In late summer there are occasional typhoons attended by heavy rain and resulting in a secondary maximum in August. In this region the northeast winds of winter have passed over considerable distances of warm water and have absorbed a good deal of moisture in their lower portions. This makes for instability and

Climates of China, Manchuria, and Japan	Elevation (Feet)	Mean Temperature, °F. Year	Coolest month	Warmest month	Range	Av. Precipitation (Inches) Year	Wettest month	Driest month
STH								
Hong Kong, China	108	71.6	Feb. 57 7	July 81.7	24.0	84.3	June 15.9	Dec. 1.1
Chengtu, China	1510	61.9	Jan. 43 9	July 79.2	35.3	....	....	....
Taihoku, Formosa	30	70 9	Feb. 57 2	July 82 2	25.0	83.0	Aug. 11 8	Nov. 2.7
Kagoshima, Japan	394	61.5	Jan. 44 6	Aug. 79 5	34.9	84.7	June 13 9	Feb. 3.3
ICw								
Hankow, China	118	61.9	Jan. 39.6	Aug. 83.3	43.7	49 6	June 9.6	Dec. 1.1
Shanghai, China	33	60 4	Jan. 37 8	July 80.4	42.6	45.1	June 7.3	Dec. 1.4
Peiping, China	130	52.3	Jan. 23.2	July 77 5	54.3	24.9	July 9.4	Jan. 0.1
ICc								
Mukden, Manchuria	144	44 6	Jan. 9.0	July 75.9	66.9	26.4	July 6.3	Jan. 0.2
Harbin, "	525	37.9	Jan. −1.7	July 72.1	73.8	19.3	July 4.5	Jan. 0.1
Vladivostok, Siberia	50	40.3	Jan. 7.3	Aug. 69.1	61.8	....	....	....
ICm (*east coast of Japan*)								
Tokyo	70	56.8	Jan. 37.4	Aug. 77.7	40.3	59.9	Sept. 8.7	Dec. 2.1
Miyako	98	50.1	Jan. 30.9	Aug. 71.6	40.7	55.3	Sept. 8.5	Dec. 2.7
Nemuro	89	42.1	Feb. 22.3	Aug. 62.6	40.3	37.8	Sept. 5.5	Feb. 1.0
ICm (*west coast of Japan*)								
Nagasaki	436	60.3	Jan. 42.3	Aug. 79 9	37.6	76.9	June 13.5	Jan. 3.1
Niigata	85	54.5	Feb. 34.3	Aug. 77.7	43.4	70.6	Dec. 9.1	May 3.7
Kanazawa	95	....	....	....	....	99.7	Dec. 14.4	May 6.1

probably accounts for the winter rains which amount to one or two inches per month. Thunderstorms attend the typhoons, but at other times they are not numerous. The average number is

thirty to fifty a year. The number of rainy days averages 143 per year at Hong Kong and 186 at Taihoku. Monsoon rains are variable, but there is seldom any real drought. In favored localities such tropical products as bananas, pineapples, mangoes, and coco-

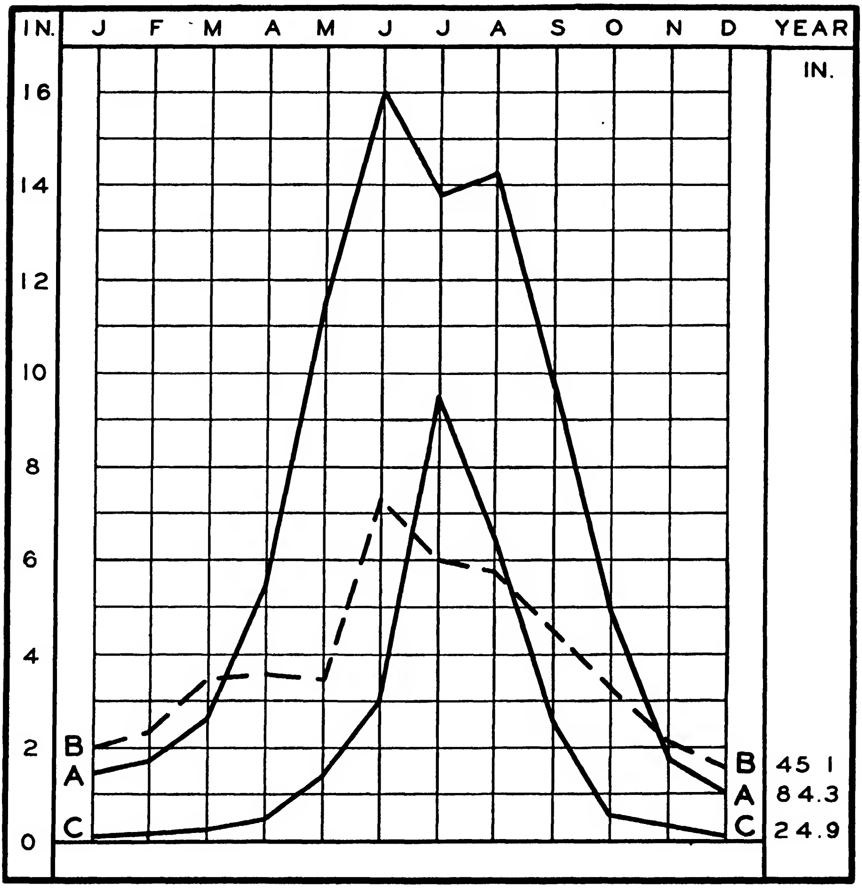

FIG. 83—Average Precipitation. Subtropical and warm intermediate climates of China.

A. Hong Kong (STH). B. Shanghai (ICw). C. Peiping (ICw).

nuts are grown. The principal crops, however, are those typical of subtropical climates—sugar cane, tea, rice, yams, and fruits.

From this coastal region northward to the Yangtse River and across the river into the Red Basin of Szechwan (the soil is red) the same type of subtropical climate continues, but with gradually decreasing winter temperatures and decreasing rainfall. The annual rainfall near the Yangtse Kiang, amounting to forty or fifty

inches a year, is about half of that on the southern coast. About 80% of it falls in the seven months from April to October. It is mainly an accompaniment of the southerly summer monsoon, and is heaviest in June; a secondary maximum in September is due to the typhoons, which are most frequent in late summer. These storms lose their destructive violence as they move inland, but they cause continuous heavy rain, sometimes lasting two or three days. (The same is true of hurricanes entering the Gulf States of America.) Winter rainfall in the interior is less than one inch per month.

In the southwestern Chinese provinces of Kweichow and Yunan the plains and tablelands up to elevations of a few thousand feet are subtropical, but there are considerable areas of mountains and highlands with colder climates. This region is drier and sunnier than the other parts of China south of the Yangtse Kiang, but it has a rainy season about five months in length, May to September. Poppy, tea, tobacco, rice, sugar cane, and cotton are grown. The higher tablelands produce wheat, corn, and soybeans.

Japan

The irregular southeast coast of Japan to latitude 35° N. is a cool, subtropical area with heavy rainfall. (See Kagoshima in table.) The winter temperatures are 12° to 15° lower than on the southern coast of China or in Formosa, but summer temperatures are only slightly lower and the annual range is about 10° greater. Freezing temperatures occur occasionally in winter; summer temperatures seldom exceed 100°. The rainfall is variable in annual amount, but exceeds eighty inches in places. It is heaviest in summer, but the winter months receive moderate amounts and there is no dry period. This applies, at least, to the wetter situations; local exposure makes some areas dry.

The population is dense and makes intensive use of the land, irrigating the drier portions and often producing two crops a year. In this subtropical portion of Japan tea and rice are the major crops, and considerable tobacco is grown. In some provinces the poppy and mulberry are cultivated, and in protected coastal situations palms and oranges flourish.

The Ryukyu Islands have a climate similar to that of southeast Japan, but wetter. These islands are cool for their latitude.

The coolest month is February, with a mean of 58°; the warmest is August, averaging 82°. Heavy rain is received from both summer and winter monsoons. The winter winds are especially steady, and rain falls almost every day during the winter. Typhoons are frequent in late summer. The principal crops are sugar cane and sweet potatoes. Some tropical fruits are grown.

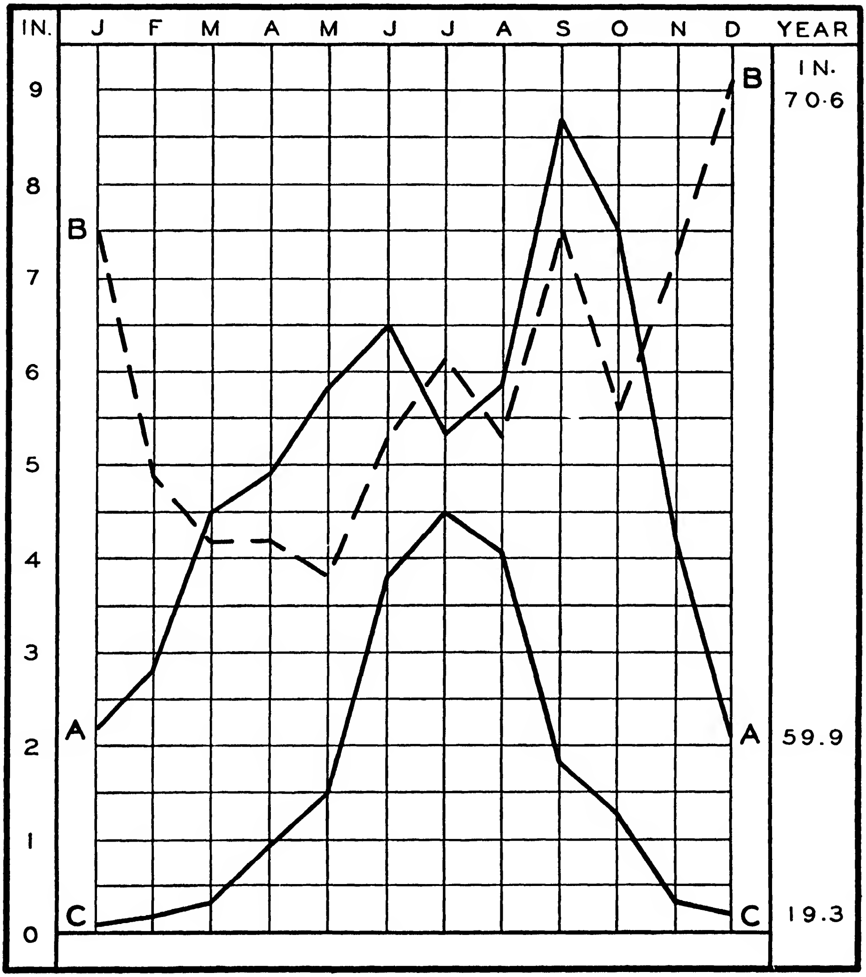

FIG. 84.—Average Precipitation. Intermediate climates of Japan and Manchuria. A. Tokyo (ICm). B. Niigata (ICm). C. Harbin (ICc).

The Warm, Humid Continental Climate of Northern China (ICw)

The northern half of China—that portion between the parallels of 30° N. and 40° N., approximately—has a continental cli-

mate with short, cold winters and long, warm summers (ICw type). The peninsular part of Chosen (Korea) is of the same type. It is the type that is found in the United States from the eastern portions of Nebraska, Kansas, and Oklahoma eastward to the Atlantic coast, between latitudes 34° N. and 44° N. Shanghai, at the mouth of the Yangtse River, has three months with mean temperatures below 43°, the coldest being January, which has a mean of 38°. Hankow, farther inland on the Yangtse, is slightly warmer than Shanghai, but it, too, has three months slightly below 43°. Peiping (Peking), at the northern boundary of the region, has three months averaging colder than 32°, and the January average is 23°. These values indicate the range of temperature conditions included in this climatic type. A minimum of 10° has been recorded at Shanghai and 13° at Hankow; temperatures below zero occur occasionally in the north. Note the considerable decrease in temperature between Shanghai and Peiping. The decrease is less rapid, however, than in corresponding latitudes on the Atlantic coast of the United States—for example, from Charleston to New York.

The winter monsoons from the northwest or north are strong and persistent in this region, particularly near the coast. Hence there is practically no moderating marine effect during the winter. Because it is better protected from the monsoons by mountain ranges, much of the interior has lighter winds. This accounts for the unusual fact, illustrated by Shanghai and Hankow, that the winters are colder on the coast than in the interior. These polar continental winds descend from the high deserts and steppes of Mongolia and Siberia and are therefore very dry. Although it is warmed by descent, the air remains cold because of the abnormally low temperatures it acquires in inner Asia. These winds also travel over large areas of fine-grained loess soil, and in consequence they are often dusty. A dry haze is practically continuous, and dust storms are frequent both in Chosen and in the Hwang Ho Basin. (The latter, the Yellow River Basin, is so called because the loess silt that it carries colors the river yellow.) The winter monsoon begins in October and continues into April.

The summer monsoons are from the southeast or south throughout the region, but are weaker than the winter winds and more variable from year to year. They are composed of tropical

maritime air of high temperature and high humidity. Maximum temperatures above 100° occur occasionally and nights are often warm and muggy, for the daily range of temperature is only 20° to 25°. As a result of the seasonal reversal of air currents the summers have considerably higher relative humidities than the winters, and therefore, much greater specific humidities. The southerly winds of the summer monsoon prevail from May to September.

The annual rainfall decreases from about forty-five inches along the Yangtse River to about twenty-five inches at Peiping. It also decreases westward to about twenty to twenty-five inches in the western interior. As a result of the monsoonal circulation described in the previous paragraphs the rainfall is strongly concentrated in the summer months during the prevalence of southerly winds. This is especially true in the northern plain drained by the Hwang Ho. At Peiping 85% of the annual total falls in the four months, June to September, and 63% in the two months of July and August. The period from October to April has a total of only 2.2 inches. The concentration is not nearly so marked in the Yangtse Basin, where moderate rains occur throughout the winter. These are associated with barometric depressions that form along the boundary between the high pressure center and the subtropical belt of low pressure, where strong temperature contracts produce frontal activity. These depressions move down the Yangtse Valley, and are often followed by cold waves and blizzards.

In northern China the summer monsoon is erratic, and the period in which heavy rain may be expected is short. In years when the monsoon is strong and persistent, there are often disastrous floods in the valley of the Yellow River; in years when the winds are weak there are often severe droughts. Both floods and droughts may cause extensive famines. In the west the loess highlands bordering on Inner Mongolia are dry and dusty, and approach semiarid conditions. No part of China north of the Yangtse is much subject to the influence of typhoons; such storms usually dissipate or turn eastward before reaching these latitudes.

The center of the cotton belt of China is in the subtropical region on the south bank of the Yangtse River, but the provinces on

the north of the river produce some cotton and also tea and rice. These summer crops are frequently followed by fall-sown grains for spring harvesting. The Yellow River Basin may be considered the corn belt of China. In addition to corn it produces tobacco, wheat, grain sorghums, and soybeans; some raisins, grapes, pears, plums, and apples are also raised.

The Cold Continental Climate of Manchuria (ICc)

The region between latitudes 40° N. and 54° N., comprising Sakhalin, southeastern Siberia, and practically all of Manchuria, and extending westward to the Mongolian steppes, has a climate of severe winters and short, hot summers (ICc type). Its climate resembles that of Minnesota, the eastern parts of the Dakotas, and adjacent portions of southern Canada. The annual rainfall is twenty-five inches or less; there are four or five winter months with mean temperatures below 32° and four or five summer months averaging warmer than 50°. The growing season is about 100 to 140 days in length. The strongly monsoonal character of the Manchurian climate differentiates it, however, from the same type in North America. The differences are particularly evident in the annual march of temperature and precipitation. (See Harbin, Fig. 84.) The winter monsoons over the region are steady, strong, cold, and dry northwest winds attended by cloudless but often dusty skies. The southeast monsoons prevail for about five months of summer, but they are unequally developed from year to year, and are frequently weak.

As is characteristic of continental climates, there is little latitudinal change in temperature in summer, but there is a marked poleward decrease in winter. This characteristic is more marked in Manchuria than in North America. In July Harbin is only 5° cooler than Peiping; in January it is 25° colder. Harbin is somewhat warmer at all seasons than Winnipeg, but its annual range is 4° greater. Mukden has the same average annual temperature as Minneapolis, but its summers are warmer, its winters colder, and its annual range 9° greater, although it is 4° of latitude farther south and close to the sea. In summer, the daytime temperatures are not unusually high, seldom exceeding 100°, but the nights remain warm. In winter minimum temperatures as low as —20° are to be expected in southern Manchuria, and —25° in the north.

The annual rainfall in this Asiatic region, which is about the same as that in Minnesota and the Dakotas, approaches semiarid conditions in the north and west. The rainfall has a July and August maximum instead of the usual May and June maximum of continental climates, and the distribution is, therefore, somewhat less favorable for the production of crops. The control is monsoonal rather than cyclonic. The winter months are almost rainless. Mukden has three inches less rain per year than has Minneapolis; July, August, and September are wetter at Mukden, but all other months are drier. At Harbin 64% of the rainfall occurs in June, July, and August. Soybeans have become the principal export crop of this region, which also produces spring grains, indigo, and opium. In addition, there are large areas of grassland.

The Modified Continental Climate of Japan (ICm)

Japan is a mountainous country and only about 12% of its area is agricultural. The cultivated portion is in the narrow coastal plains and in small separated valleys and basins between the hills. The greater part of the country, therefore, has a mountain climate with many gradations closely related to elevation and slope, but the dense population is confined to the level areas which are low or of moderate elevation. These areas are accordingly of greatest importance, and it is their climate that will be discussed here as the climate of Japan.

Japan is subject to the same monsoon winds which control the climate of northern China and Manchuria, but because it is composed of narrow, elongated islands, it feels also the influence of the surrounding waters. The northwest monsoons are cold and dry when they leave the mainland of Asia, but they are considerably warmed and moistened by their passage over the Sea of Japan. (It will be remembered that the eastern side of this sea receives a current of warm water from the Kuro-shio.) Japan is, therefore, considerably warmer and wetter in winter than corresponding latitudes in China and Manchuria. The southeast monsoons of summer from the warm Pacific Ocean reach Japan first with their marine characteristics unchanged, and they make the summers warm and moist except in the extreme north. Because these influences result in a climatic type that is neither strictly marine nor entirely continental, the climate is called a *modified continental climate* (ICm). If we consider Japan as extending from Formosa

to Karafuto (the southern half of Sakhalin), we have a range in latitude and a range in climate similar to that from Cuba to Newfoundland. But we are here considering only the main islands of Japan proper between latitudes 31° N. and 46° N. These have climatic types changing from the humid subtropical along the southeast coast, previously discussed, to the warm humid continental and the cold humid continental, both with marine modifications and here combined into the one type, *modified humid continental.*

Temperature

One modification is seen in the lower annual range of temperature, especially in the warmer winters. Nagasaki has the same mean annual temperature as Shanghai, but the summers average about 1° cooler and the winters are about 4° warmer than at Shanghai. The annual range is 38° at Nagasaki and 44° at Shanghai. At Niigata the range is 43° and at Peiping it is 54°; the difference in range is due entirely to the warmer winters in the Japanese city. Another marine influence is felt in the delayed occurrence of the maximum and minimum temperatures. In China, as in continental interiors in general, January is the coldest month and July the warmest; in Japan the coolest and warmest months are February and August, respectively.

The southern portion of the region, that part bordering on the subtropical southeast coast, is almost subtropical in character. At Nagasaki only January and February have mean temperatures below 43°, and these by less than 1°. In this region frosts are rare and some subtropical vegetation flourishes. The rainfall regime at Nagasaki is much like that of the Yangtse Valley in China, but amounts are greater at all seasons. The northern half of the largest island, Honshu, has winter temperatures like those of the warm continental type; the mean of the coldest month is less than 43°, but only the extreme north of this island has one or two months averaging below 32°. Tea is grown in southern Honshu, and rice, tobacco, and mulberries are produced throughout the island.

Hokkaido, the northernmost of the large islands, has decidedly cold winters. Both sides of the island have mean temperatures below 32° for four months, and there is heavy snowfall, particularly on the western side. The winters are colder than at Peiping but not so cold as at Mukden. The summers are 5° to 10° cooler than at the mainland cities, and are more like those of Portland,

Maine, or of London. Hokkaido is a spring grain region (wheat, oats, and millet), and the hills are covered with forests of oak and pine.

Rainfall

There are large variations in the amount and distribution of rainfall in Japan, depending on slope and exposure. In particular, there is a difference between the east and west sides of the islands, and on both sides the regime is different from that of corresponding latitudes in China. On the eastern slopes the difference is largely in the greater rainfall of the autumn months which is due to the influence of typhoons. We have noted a secondary maximum of precipitation in southern China in late summer or fall at the time of the greatest typhoon activity. Typhoons seldom affect north China, but many of them in their northeasterly course move across or in the vicinity of Japan. The result is that along the whole east coast from Tokyo to Nemuro (in northeast Hokkaido) September is the month of heaviest rain. There is a monsoonal, secondary maximum in June or July, then a slight decrease, and then a rise to the primary maximum in September, a combined effect of monsoon and typhoon. The typhoons are most numerous in this month and the southeast monsoon continues, although not at its height. (See Fig. 84, Tokyo.) On this coast, as in China, the minimum rainfall occurs during the winter, December to February, but amounts are somewhat greater than in north China and generally exceed two inches a month.

The west coast of Japan has a very different rainfall regime, which illustrates clearly the influence of the warm water in the Sea of Japan. Here the winters are wet, in strong contrast to the characteristically dry winters of other monsoon regions. The dry northwest winds from Manchukuo and Siberia become moist over the warm water, and they yield heavy and almost continuous rain as the air is forced upward against the westward slopes of the Japanese Islands. The records at Kanazawa and Niigata (Fig. 84) illustrate the west coast rainfall regime; at both there is a strong maximum in December and January. Also at both there is a secondary or typhoon maximum in September, and a third, midsummer maximum, in July. The month of least rainfall is May, a transition month between the winter and summer monsoons, but the rainfall is moderate to heavy in all months.

CHAPTER XIX

Climate of the Mediterranean Region

Both types of subtropical climate are represented in Eurasia. The humid subtropical (STH) of southern China has been discussed; the dry subtropical (STM) has its typical representation in the Mediterranean region of Eurasia and northern Africa. Compared to the whole area of the continent, the areas of subtropical climates are small in Eurasia, as in the other continents, but these regions are of an importance wholly out of proportion to their size. This is because of the nature of their agricultural products, and, in the case of the Mediterranean, also because of its historical importance in the development of civilization.

The coastal lands adjacent to the Mediterranean Sea have a characteristic type of climate so distinct and well-known that the name *Mediterranean climate* is applied to this type in all parts of the world. As has been noted in previous chapters, small areas in California and Chile have the same type of climate, and, as will be noted later, there are similar small areas in Africa and Australia. There are, of course, small differences of climatic conditions in these various parts of the world, but the similarities are so great that the areas are easily recognized as belonging to the same type. They are all in the same latitude, north or south; all are included between the parallels of 30° and 45°, and, more typically, between latitudes 33° and 38°. These are the latitudes which the seasonal shifting of the pressure belts brings under the influence of the subtropical highs during the summer of each hemisphere, and more or less under the influence of the prevailing westerlies during the winter. They are, therefore, subject to occasional traveling depressions in winter, but not in summer. They are all on the west coasts of continents, and are open to marine influences from that direction.

In consequence of this geographic and meteorological position, the Mediterranean type of climate, wherever found, is a marine or

littoral climate characterized by: (a) mild winters of light to moderate rainfall, because of the westerly winds and the traveling cyclones; (b) warm to hot summers, tempered by sea breezes, with a considerable period rainless or almost so; (c) abundant sunshine during both winter and summer; (d) a natural vegetation consisting of broad-leaved evergreens and drought-resistant trees and shrubs, and a characteristic type of cultivated crops, notably citrus fruits and olives; (e) mean temperature of coldest month above 43°, and, more typically, about 50°.

The region bordering the Mediterranean Sea is the most extensive and the most northerly area having this type of climate. This is largely due to the presence of the Mediterranean itself, but partly also to the existence of great mountain chains on the north, the absence of large land masses to the northwest, and the great irregularity of the Mediterranean coast line. These conditions, together with the topography of the land areas, give rise to a great many local differences of climate. There are considerable variations from place to place in mean temperatures (both summer and winter) and in the annual total of rainfall. In the subtropical regions of California and Chile the coast lines are almost straight, and high mountain ranges, trending north and south, confine the marine influences to the rather narrow coastal regions. In the Mediterranean region, by contrast, the mountains run east and west, and the sea penetrates far into the interior, extending the marine effect to a much-elongated coast line increased by peninsulas and by numerous islands.

The presence of the Mediterranean Sea results in a specialized pressure distribution and wind movement in winter. In summer the Atlantic high pressure area extends inland somewhat north of the Mediterranean, giving mostly west or northwest winds, analogous to conditions in California. These winds, however, become northeast on the African coast of the western Mediterranean. In winter one or more local centers of low pressure develop over the relatively warm waters of the Mediterranean. The winds blow from the land to the sea into these centers of low pressure and give a monsoonal effect. Thus, the winds have a general northerly direction in the northern portions of the Mediterranean and on the Turkish coast, and a southerly direction on the coasts of Africa, Palestine, and Syria. Portugal and the Atlantic coastal plain of

Morocco have a situation and a climate more closely resembling those of California and Chile. Sea breezes exercise an important moderating influence in general throughout the region. The entire subtropical Mediterranean region may be divided into six provinces. The climatic characteristics of each of these will be briefly discussed in the following paragraphs.

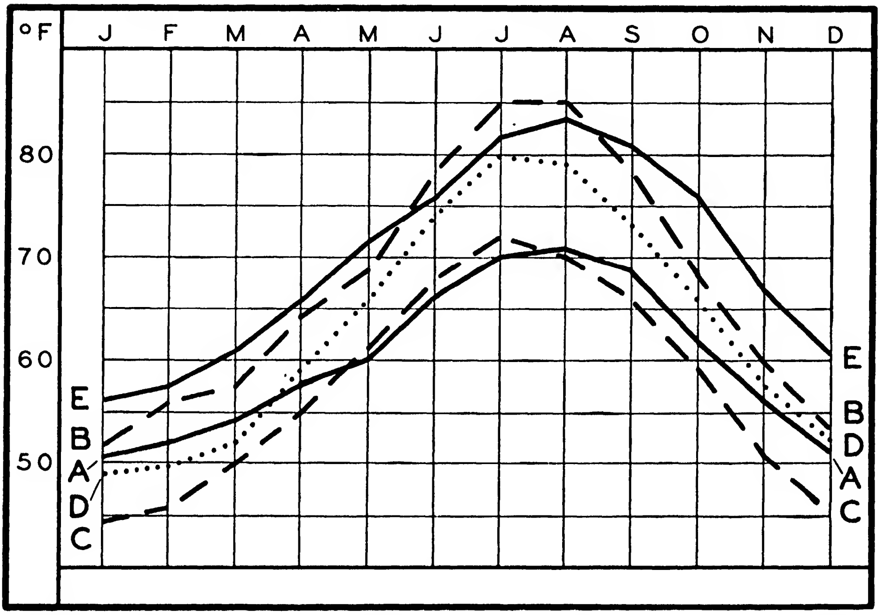

FIG. 85—Average Temperature. Subtropical climates of the Mediterranean Region.
A. Lisbon, Portugal. C. Marseilles, France. E. Beyrouth, Syria.
B. Seville, Spain. D. Athens, Greece.

Atlantic coast

The Atlantic coastal region of dry subtropical climate includes all but a narrow northern strip of the African coast southward to Mogador at latitude 31° N., and the Madeira Islands. Almost all of Portugal consists either of coastal plains or of valleys opening to the coast. The climate is subtropical marine with an annual mean temperature of 60° to 62°, ranging from a mean of 50° in January to 70° or 72° in August. The annual range is thus 20° to 22°, and the daily range is about the same. Lisbon is in the same latitude as San Francisco and has similar winter temperatures, but it is warmer in summer because the adjacent ocean waters are

warmer. The warm north Atlantic drift approaches the Portuguese coast. August and September water temperatures are 70° off the coast of Portugal, and 58° along the San Francisco coast. Dense fogs occur on the Portugal coast, but are not so numerous as on the coast of central California, again because of the difference in water temperatures. Thunderstorms are rare in both situations. The rainfall of Portugal is thirty to sixty inches, which is greater than in similar positions in Californa and Chile, probably because the winter winds are more directly on-shore. The rainfall is similarly distributed, however, except that the maximum occurs in November and December rather than in December and January. Almost all of the rain falls in the cooler half of the year, and the summers are practically rainless.

The Atlantic coast of Morocco southward to latitude 31° N. has a very equable climate with warm winters and remarkably cool summers in view of its latitude and its nearness to the Sahara Desert, from which it is separated by the Atlas Mountains. The position and the climate are comparable in many ways to those of southern California. Temperatures seldom rise above 80° in summer and are seldom below 40° in winter. Mogador has a summer mean temperature of only 68°, which is considerably cooler than at Lisbon, 7½° of latitude farther north. The reason is to be found in the cool Canaries Current, which here moves southeastward and impinges against the coast. It causes an actual decrease in temperature from north to south between the Strait of Gibraltar and Mogador. On the other hand, as has been noted, there is warm water off the coast of Portugal.

The rainfall of the Morocco coast is less than fifteen inches, and has the characteristic Mediterranean type of distribution. It is largely concentrated in the five months from November to March, and the four months from June to September are practically rainless. The prevailing winds at all seasons are the dry northeast trades, and these contribute to the evenness of the climatic conditions. In winter, however, traveling disturbances occasionally bring southwest winds, and these are the rain-bearing winds. The more sheltered valleys even a short distance inland have much higher summer temperatures than the coastal plains, as is the case also in southern California. That some of the interior valleys approach desert conditions is indicated by the presence of cacti and other desert vegetation. Where water is available the

characteristic fruits of the Mediterranean region are produced abundantly.

The Madeira Islands, 300 miles off the Moroccan coast, are volcanic islands with a central ridge bordered by narrow coastal plains and river valleys. These lowlands have a climate similar to that of the coast of Morocco. The climate is marine in its small daily range of temperature (about 10°), but note that the temperatures at Funchal, especially in summer, are somewhat higher than at Mogador. The cooler water is close inshore, and the ocean surface is several degrees warmer around the islands than near the mainland. The absolute minimum temperature of record at Funchal is 46°. The rainfall of twenty-seven inches at Funchal is local and due to its southern exposure. On the whole, the lowlands are deficient in rainfall, but heavier rains in the mountains furnish water for irrigation. The crops are mainly grapes and sugar cane, grown under irrigation. Frost and snow are unknown on the lowlands, and tropical fruits are grown.

Southern Spain and the Balearic Islands

The coastal provinces of southern and southeastern Spain (Andalusia and Murcia) are hotter and drier than the west coast regions just described. In fact, this area is the most nearly tropical portion of Europe. The mean temperature of the coldest month is about 50° or higher, and there are no cold waves. Frost and snow are hardly known. Seville, in the southwest, is fifty-four miles inland and corresponds in latitude to Fresno, California, but it is 6° to 7° warmer in winter and 3° warmer in summer than is Fresno. It has a high mean temperature of 85° in July and August. The rainfall, however, is more than twice as great as at Fresno, with more than two inches per month for six months, October to March, and with fairly good rains in April and May.

Murcia, at latitude 38° N., near the east coast, is 4° warmer than Sacramento in January and 6° warmer in August. The rainfall is light and more evenly distributed than is typical of the Mediterranean climate, because easterly, onshore winds occur in spring and autumn in this western portion of the Mediterranean. At Murcia no month has as much as two inches of rain, but nine months have more than one inch; July and August are without significant amounts. This southeast area is visited occasionally by

STM *Climate of the Mediterranean Region*	*Elevation (Feet)*	*Mean Temperature, °F.*				*Av. Precipitation (Inches)*		
		Year	*Coolest month*	*Warmest month*	*Range*	*Year*	*Wettest month*	*Driest month*
Atlantic Coast								
Lisbon	66	60.3	Jan. 50.5	Aug. 71.1	20.6	29.7	Nov. 4 5	July 0.2
Mogador	33	63.7	Jan. 57.0	Sept. 68.5	11.5	13.2	Nov. 2 4	July 0.0
Funchal, Madeira	82	64.8	Feb. 59.2	Aug. 72.1	12.9	27.2	Nov. 4.7	July 0.1
Southern Spain								
Seville	66	67.3	Jan. 52.2	Aug. 84 9	32.7	20.3	Nov. 3.1	July 0.0
Murcia	197	63 9	Jan. 50 2	Aug. 78.8	28.6	14.5	Oct. 1.9	July 0.2
Palma, Majorca	75	62 8	Jan. 50.9	Aug. 77.9	27.0	18.9	Oct. 3.1	July 0.4
Northern Mediterranean								
Barcelona	131	59.4	Jan. 46.4	July 73.9	27.5	21.2	Oct. 3.0	July 1.1
Marseilles	246	57.4	Jan. 44.3	July 71.8	27.5	22.6	Oct. 3.9	July 0.7
Genoa	177	59.9	Jan. 45.5	July 75.4	29.9	52.0	Oct. 7.8	July 1.7
Rome	164	59.7	Jan. 44.6	July 76.1	31.5	32.7	Oct. 5.0	July 0.7
S. Italy, Greece, E. Adriatic								
Sassari, Sardinia	....	59.9	Jan. 46.6	July 74.3	27.7	23.6	Nov. 3.7	July 0.3
Palermo, Sicily	230	63.1	Jan. 50 5	Aug. 76.6	26.1	29.5	Dec. 4.5	July 0.3
Naples	492	60.4	Jan. 46 8	July 75.6	28.8	33.0	Nov. 4.6	July 0.6
Ragusa (Dubrovnik)	49	61.7	Jan. 47.7	July 77.0	29.3	59.2	Nov. 7 8	July 1 3
Corfu	98	63.9	Jan. 50 4	Aug. 78 6	28.2	47.9	Dec. 8 3	July 0 4
Athens	351	63.1	Jan. 48.4	July 79.9	31.5	15.5	Dec. 2.6	July 0.3
Asia Minor, Syria, Palestine								
Constantinople	246	56.8	Jan. 40.6	July 73.2	32.6	28.9	Dec. 4.8	July 1.1
Smyrna	66	....	....	....	....	19 8	Dec. 3.7	July 0.0
Beyrouth (Beirut)	111	70.0	Jan. 56 5	Aug. 83 1	26.6	35.5	Dec. 7.5	July 0 0
Jerusalem	2460	60.6	Jan. 44.8	July 73.2	28.4	24.8	Jan. 6.3	July 0.0
African Coast								
Algiers	72	60.6	Jan. 49.3	Aug. 74.7	25.4	27.4	Nov. 4.1	Aug. 0.1
Tunis	141	63.1	Jan. 48.4	Aug. 78.6	30.2	16.5	Dec. 2.4	July 0.1

the dry, hot *sirocco* (locally called *leveche*) from Africa, which corresponds somewhat in character—although not in origin—to the "northers" of the Sacramento Valley. The Balearic Islands have a climate very like that of the southeast coast of Spain. The win-

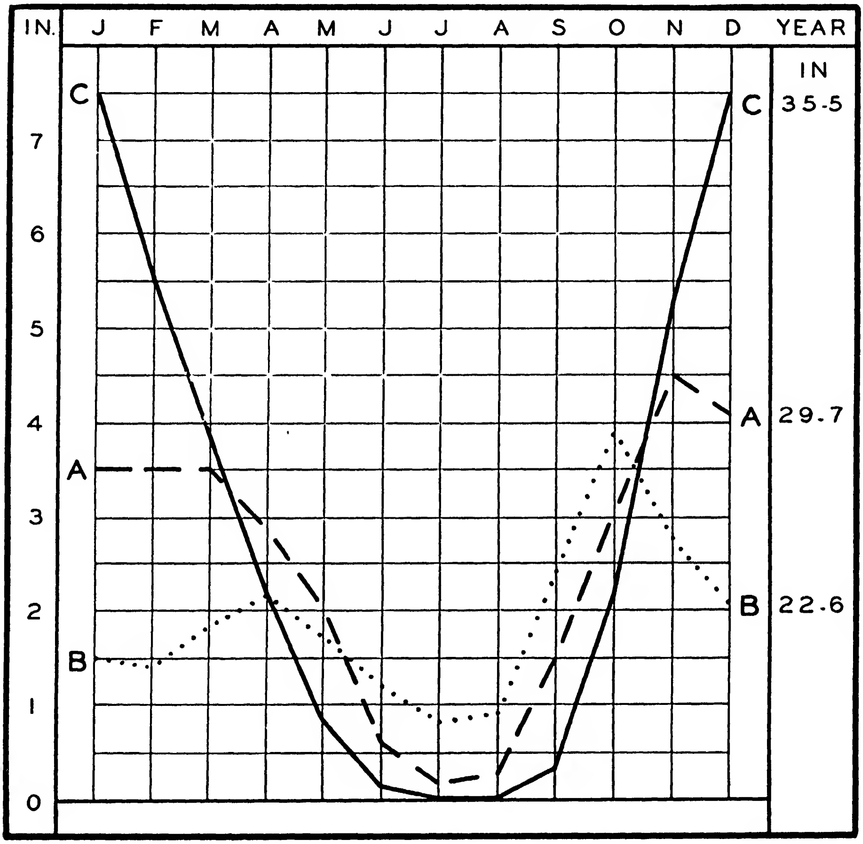

FIG. 86—Average Precipitation. Subtropical climate of the Mediterranean Region.
A. Lisbon. B. Marseilles. C. Beyrouth.

ters are warm and the summers are hot, and the rainfall is distributed as in the Murcia region.

Much of southeast Spain has a desert aspect, especially in summer when the grasses have withered, and an area extending inland between Murcia and Malaga may be included in the steppe climatic province of central Spain. Under irrigation southeast Spain becomes a land of orchards and vineyards. Various regions are famous for their oranges, grapes, wines, or other subtropical products, and even such tropical fruits as dates and bananas are grown in

places. There are many areas where the native covering of the soil is a tangled mass of small trees, shrubs, and vines. The thicket so formed is known as *maqui*.

Interior Spain

The greater part of the interior of Spain is a tableland of about 2,600 feet elevation, bounded on the north and south by mountain ranges and crossed by other mountains. These extensive elevated plains are deficient in moisture and have large extremes of temperature. Their climate is of the middle latitude steppe type (IS). In summer the daytime temperatures are high, but there is rapid radiation cooling after sunset and the nights are cool. The July mean temperatures are therefore not extreme—about 73° to 76°. In winter also there are large daily ranges of temperature (about 30°), with frequent freezing weather and with occasional temperatures as low as 15°. January mean temperatures are 36° to 42°. The summers are almost rainless, with low humidity and mostly clear skies; the air, however, is often hazy and dusty. There are two about equal rainfall maxima, one in April or May and another in November, but the wettest month has less than two inches of rain, and the annual total is between ten and twenty inches. There are treeless plains, but large tracts are covered with evergreen shrubs; other extensive regions are sunburnt wastes in summer, almost desert-like in appearance. As has been previously stated, steppe-like conditions extend southeastward to the Mediterranean coast between Murcia and Malaga.

Northern Mediterranean coast

The regions here considered are the coastal plains extending from about latitude 39° N. in eastern Spain northward and eastward to about latitude 44° N. at Genoa and thence southeastward to about latitude 41° N., a little south of Rome. These areas are several degrees cooler in winter than are southern Spain and Portugal, and they are subject to freezing temperatures at least once a year. They have recorded minima of 20° or lower. The summers also are cooler than in southern Spain. The January temperatures average 43° to 46°, and the July temperatures average 72° to 76°. These temperatures are much the same as in the interior valleys of central California, but, because of the more di-

rect marine influence, the summer maxima are not as high as in California. The typical Mediterranean flora flourishes throughout this coastal region, although it is often intermingled with plants such as oak, beech, and chestnut, which are more characteristic of interior Europe.

The rainfall is light on the Spanish and French coasts, amounting to between twenty and twenty-five inches a year. It is heavy for this climatic type on the Italian coast, amounting to thirty-two to fifty-two inches a year. The rainfall is greatest in the winter half-year, but some rain falls throughout the summer. The maximum occurs in October, a month or two earlier than in other parts of the Mediterranean and three months earlier than in California. In places there is a secondary maximum in April. The reason for the greater rainfall and its extension over a greater part of the year is to be found in the latitude of the region. It is unusually far from the equator for a subtropical type of climate, and is subject to the influence of traveling cyclones through a greater portion of the year. Because of the relatively high latitude, the storms begin earlier in autumn and continue later into spring, and they even occur occasionally in summer. The latitude is that of Oregon and northern California, and the rainfall regime is more like that of Oregon than that of the subtropical part of California. Genoa is at the head of a gulf and has mountains in the immediate background, and the prevailing winds are onshore from October to May. Under these particularly favorable conditions it has an annual rainfall of fifty-two inches, and even the driest month, July, has 1.7 inches.

Occasionally, in winter, abnormally cold air accumulates over the Central Plateau of France and then flows southward down the Rhone Valley, reaching the French Mediterranean coast as a strong, cold, dry, north wind called the *mistral*. A similar wind occurs less frequently eastward to Genoa and southwestward to northeast Spain. This is the most disagreeable feature of the climate of the area. From the vicinity of Cannes, France, to Spezia, Italy, the Maritime Alps and the northern Apennines extend practically to the coast, leaving a coastal strip only a few miles wide, which is thus effectively protected on the north and east from the cold air of the continental interior. This is the Riviera, a favorite European winter resort. It has an unusually mild climate for

such a northerly latitude and also an unusually sunny one in spite of its rather heavy rainfall. Freezing temperatures are rare, and in sheltered places even the banana and the date palm may be grown.

From the Riviera southward to beyond Rome the immediate coast has a climate very similar to that just described, a little drier than the Genoa region but wetter than the French and Spanish coasts. Freezing temperatures occur frequently enough to prevent the full luxuriance of subtropical vegetation found in southern Spain and southern Italy, but not to prevent the cultivation of olives, grapes, and mulberries. Inland, conditions rapidly become more continental, and the winters especially become colder as the elevation increases. The Apennines extend the length of Italy, and in their central portion rise to elevations of more than 5,000 feet. They have heavy snows in winter and frosts even in midsummer. The interior of Italy therefore has a highland climate with all the variations from subtropical at the base of the mountains to intermediate at the higher elevations. Florence, in the interior, but with an elevation of only 240 feet, has two months, December and January, with mean temperatures below the subtropical limit of 43°.

The islands of Corsica and Sardinia are largely mountainous and thus they, too, have a great variety of local climates which become rather rigorous at the higher levels. The lowland areas, however, have a climate similar to that of the Spanish and French coasts, although it is somewhat moister and more disagreeable in summer. The mean temperature is about 48° in winter and 73° in summer—approximately the same in both seasons as at Barcelona. About twenty-five inches of rain falls per year in Corsica and northern Sardinia, and more in southwestern Sardinia and in the mountains. There is abundant water from the mountains for irrigating the cultivated areas which produce citrus fruits, olives, and grapes. Grape culture extends to a considerable elevation on the mountain slopes.

Southern Italy, Greece, and the northern Adriatic

In Greece and southern Italy the subtropical Mediterranean climate reaches its complete development. The mean temperature of the coldest month is 47° to 50°, and frosts are rare. The sum-

mers are hot and dry, but not as hot or as dry as in southern Spain. The rainfall has a single maximum in November or December, but there is some rain in all months; sunshine is abundant in all seasons. Subtropical vegetation grows luxuriantly, with injury by low temperatures infrequent. This applies to the coastal lowlands. Throughout the region there is considerable contrast between these plains, which are directly under marine influence, and the interior and more elevated lands.

Southern Italy is largely free from storms and cold winds, but is subject to occasional siroccos from the Sahara. In crossing the Mediterranean these winds absorb considerable moisture, and they reach Sicily and Italy warm, muggy, and oppressive. On the whole, the weather changes little from day to day, and bright, sunny days are the rule throughout the year. The rainfall averages about thirty inches a year, which is considerably more than in southern California. It is somewhat heavier on the west coast than on the east. Two-thirds or more of the annual total falls in the six months from October to March. Along the coast there are almost continuous groves of orange, lemon, citron, and other subtropical trees. The live oak, arbutus, and oleander grow wild. A few miles inland and up the slopes of the mountains the characteristic natural vegetation changes to oak and chestnut, and still higher, to fir and pine. The mountain valleys furnish much summer pasture at the time that the unirrigated lowlands are dry and seared.

Greece has a mean winter temperature about the same as that of southern Italy, but it is subject to occasional cold north winds, which are absent from southern Italy. The cold winds move southward from the large elevated land masses of the Balkan region. In summer Greece is somewhat hotter than southern Italy. The warm air is brought by northerly winds blowing out of the interior subtropical ridge of high pressure toward the African low. These are known as *Etesian* winds, and they blow quite regularly in July and August. In autumn the pressure gradient is occasionally reversed and the hot sirocco overspreads Greece. The topography is irregular and largely hilly or mountainous, and there is therefore a great variety of local climatic conditions. The greater part has less than twenty inches of rain, three-fourths of which

falls in the winter half-year. The rain is borne on south or southwest winds as traveling lows move eastward north of Greece. Except for thunderstorms at long intervals, the summers are almost rainless, and are monotonously hot and sunny. The grasses wither, fields are parched, streams dry up, and except for the irrigated fields, the landscape takes on a desert-like appearance. Similar conditions obtain in some of the hotter and drier inland valleys of southern California. The heat is more oppressive in the enclosed inland valleys than on the coasts where the sea breezes are better developed.

With the coming of the rains and cooler weather in the autumn there is a sudden brightening of vegetation, and the appearance of the landscape is in marked contrast to that of summer. Then, throughout the winter, the fields remain green and the orchards continue to grow. The northwest coast of Greece, represented by the record of Corfu, has a much heavier winter rainfall and a much shorter summer dry season than the rest of the peninsula, and it does not assume the arid aspect described above. In general, the annual rainfall is greatest in the islands off the west coast, including Corfu, and is least on the Aegean coast and in the islands of the Aegean Sea. The occasional relatively cold northerly winds of winter, mentioned above, are rarely attended or followed by frost, and the same subtropical fruits and flowers characteristic of southern Italy flourish throughout the Greek peninsula.

The eastern shore of the Adriatic is protected from much continental influence by its mountainous character. In places the mountains rise abruptly at the water's edge. The Mediterranean climate here extends northward to latitude 45° N., with only slight reduction in temperature as compared with Greece. This coast, however, is subjected to occasional invasions by the *bora,* a cold fallwind that descends from the highlands. The rainfall is heavier because of the mountains and the more northerly latitude, but its distribution is much the same as in other parts of the Mediterranean region. The total at Dubrovnik (Ragusa) is almost sixty inches, about half of which falls in four months, October to January. The Mediterranean mildness and the subtropical flora are confined to the sheltered valleys of the littoral; the inland plateaus are much cooler and much drier.

Asia Minor

Nearly all of Asia Minor is a semiarid plateau, previously discussed, but near the coasts the land descends abruptly, forming a narrow coastal border of lowlands. It is only this coastal strip in which a Mediterranean type of climate is found. Most of Asia Minor's Black Sea coast receives cold winter winds from the interior and is slightly too cold to be included properly in this type of climate. Constantinople, for example, has a mean temperature of 41° in January and February. The vine is grown along the entire northern coast of Asia Minor, but in most places, apples, pears, and cherries replace the subtropical fruits. Parts of the eastern half of this coast, however, are better protected by the mountains on the north and the east and have a typical dry subtropical climate. In the vicinity of the ancient city of Trebizond (Trabzon) the characteristic vegetation of the Mediterranean flourishes.

The south and west coastal fringes of Asia Minor are definitely Mediterranean in character, with only occasional frosts in winter and with hot, dry summers. The rainfall is twenty to twenty-five inches a year, largely in winter and spring. Maximum temperatures are rarely above 100° on the west coast, but rise to 110° on the south coast. Mean summer temperatures are high, however, on both coasts. Smyrna, on the west, has a July mean of 81°; its January mean is 46°. The northern part of the west coast does receive some cold continental air, and it is cooler in winter than are corresponding latitudes in Greece, Italy, and Spain. In summer the afternoon heat is regularly relieved by strong sea breezes. Smyrna is famous for figs; other products of these coasts are olives, citrus fruits, and sugar cane.

Palestine and coastal Syria

The lands on the northern shore of the Mediterranean Sea receive appreciable amounts of rain in summer, as has been noted. In considering Palestine and the coastal region of Syria, we return to a rainfall regime like that of western Morocco, southern Spain, and southern California—a regime of rainless summers and of marked concentration of a moderate rainfall in the four or five colder months. The summer winds along this eastern shore of the Mediterranean are prevailingly from the northwest out of the European ridge of high pressure toward the Asiatic center of low pres-

sure. They are composed of continental air moving southward to warmer latitudes, and they are therefore dry. Winter winds are variable, but are prevailingly composed of moist maritime air from the west. This air releases moisture as it moves inland against rising ground, particularly in connection with barometric depressions moving eastward along the southern coast of Asia Minor. These are effective in giving the Syrian coast a moderate rainfall, but few of them extend their influence southward over Palestine. Accordingly, the rainfall decreases considerably from north to south.

Precipitation is heaviest on high westward-facing slopes along the Syrian coast, where it reaches forty-five inches in places. It decreases in the inland valleys, and particularly on the eastern slopes of the mountain chain. These slopes descend to the steppe region of inner Syria, an extensive, treeless, rolling tableland furnishing much pasture for cattle, horses, camels, sheep, and goats. Along the coast of Palestine the rainfall decreases southward from twenty inches at Haifa to twelve inches at Gaza. South of Gaza there is a rapid transition to the desert conditions of the Sinai Peninsula, and only about three inches of rain a year. Back of this maritime plain is a sandy, stony plateau of moderate elevation, the birthplace of the Christian religion. Its natural vegetation consists largely of grasses and shrubs, and there are many bare rock slopes and much thin soil. There are, however, some fertile and well-watered valleys in which olives and vineyards thrive in addition to small grains, cotton, and tobacco. Of the 25.5 inches of rain at Jerusalem, seventeen inches fall in December, January, and February. During the rainless summer, June to September, the grasses wither, and only irrigated crops make any growth.

East of this elevated region is the narrow rift valley of the Jordan, a barren, almost uninhabited region the lowest portion of which is several hundred feet below sea level. This has a steppe or desert climate rather than a Mediterranean climate. Rainfall is less than ten inches a year (eight inches at Jericho), and temperatures are extremely high. Tiberias, 653 feet below sea level, has five months with mean temperatures above 80°, and August has a mean of 87°. Maximum temperatures of 120° have been recorded. The coolest month is January, which has a mean of 55°. The deepest portion of this depressed valley is occupied by the Dead Sea. East of the valley is the plateau of Trans-Jordan, in which

there is a transition to the cool steppe climate of the upper Euphrates Valley.

Temperatures also show considerable variations from the coast to the interior, but the variation from north to south is small. The entire coastal region of Syria and Palestine is decidedly warm during both winter and summer. The summers have two or three months of mean temperatures above 80°, and they are hotter than the summers of any other part of this climatic province except southern Spain. January, the coldest month, averages 55° or more, and is exceeded in this province only on the Atlantic coast of Morocco. As is indicated by the high January temperature, even light frosts are rare. The cold northerly winds of winter characteristic of the northern shore of the Mediterranean rarely reach this eastern shore, and are not so cold when they do reach it. The parching siroccos also are less frequent here than farther west, but some occur, especially in spring. Land and sea breezes are a regular and important feature of the climate. On the western plateau temperatures are about 10° lower during both winter and summer. (Compare Beyrouth and Jerusalem.) Winter temperatures are still within the subtropical limits, however, and permit continuous growth, although frosts are not uncommon. Summer maxima are not often above 90° at Jerusalem. This east coast of the Mediterranean is a land of the vine and the olive under irrigation; without irrigation it is a pasture land where goats and sheep are more numerous than cattle.

The African coast of the western Mediterranean

On the southern shore of the Mediterranean Sea the Mediterranean type of climate is confined to the coastal regions of Morocco, Algeria, and Tunisia. The actual coast line is hilly and rugged, but there are occasional flat and sandy plains. This irregular terrain extends inland at a moderate elevation for a distance of thirty to 100 miles, and contains many fertile valleys and alluvial plains. This region enjoys a truly Mediterranean climate suggesting that of southern Italy and southern Spain, and it has similar flora, including olives, prickly pears, mimosas, and oleanders. Back of this region are the steppe-like plateaus and the Atlas Mountains, which serve as the northern boundary of the Sahara Desert.

Temperatures at Algiers, during both winter and summer, are similar to those at Naples, and Tunis has temperatures much like those at Athens. The prevailing winds of summer are northeasterly and moderate, so that maximum temperatures do not reach 100° except when these Mediterranean breezes are interrupted occasionally by a sirocco from the Sahara. Here the siroccos are hot and dry and fill the air with fine sand. The summers are more nearly rainless and cloudless than in Greece or Italy, but an occasional east wind brings dense and sudden fogs along the coast of Algeria. In winter the winds are mainly westerly and the rains are brought by the traveling depressions of the Mediterranean. There is an absence of cold continental air, and frosts are rare. The annual rainfall is twenty-five to thirty inches on the Algerian coast, and about fifteen to twenty inches on the north coast of Tunisia. The east coast of Tunisia is hotter and generally drier, and has an average rainfall of about seventeen inches. About 75% of the rain falls between October and March. Summer ends with the first rains early in October, and the grasses spring up into rapid growth. Growth continues and flowers bloom throughout the winter, but with the coming of May the landscape becomes parched and brown again. Some of the sheltered valleys where water is available are famous for their orange groves and vineyards.

CHAPTER XX

Humid Intermediate, Subpolar, and Polar Climates of Europe and Siberia

Between the Mediterranean climatic province and latitude 60° N. Europe has intermediate types of climate of moderate temperatures and moderate rainfall which are well-suited to the development of energetic peoples. North of latitude 60° N. in Europe, and north of the great steppe and desert region of inner Asia, the climates are mainly subpolar or polar, unsuited to the support of a dense population or to the development of an advanced culture.

The Marine Climate of Western Europe (IM)

The middle latitude west coast marine type of climate (IM) has its greatest extent in western Europe. This is due to a combination of causes, namely: strongly prevailing westerly winds throughout the year; abnormally warm water in the north Atlantic in winter; the very irregular nature of the western coast of Europe; and the absence of high mountain barriers across the westerlies, except in Norway. In winter the Iceland Low is strongly developed and extends from Greenland to north of Norway. South of this deep low pressure center, between it and the weak subtropical high pressure belt of the Atlantic, there is a strong cyclonic circulation, giving western Europe in winter prevailingly southwest winds, warm and moist from the middle Atlantic Ocean. These are subject, however, to rather frequent interruptions by traveling depressions moving eastward across the Atlantic. These lows are attended by northeast winds in their northeastern sectors and by southeast winds in their southeastern portions.

In summer the Iceland Low is much weakened, but there is a strong center of high pressure in the vicinity of the Azores which results in an anticyclonic circulation and in cool west to northwest winds across western Europe. Marine influences are thus carried far inland during both winter and summer. Because abnormally

warm water extends far northward in the Atlantic in winter, the southwesterly winds reach the coast with almost the same temperature regardless of latitude; the temperature decreases inland, however, and hence the winter isotherms run almost north and south. In summer the temperature rises with distance from the ocean, and there is also some rise from north to south. Hence the trend of the summer isotherms is from southwest to northeast.

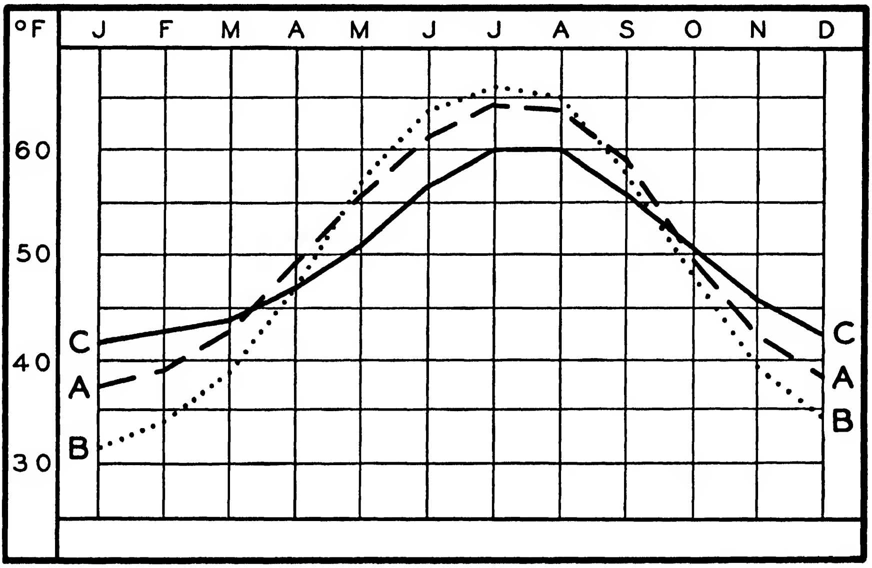

FIG. 87—Average Temperature. Intermediate marine climate of western Europe. A. Paris. B. Berlin. C. Dublin.

The distinguishing characteristic of a marine climate is a small annual range of temperature resulting from relatively mild winters and cool summers. For purposes of classification, the intermediate west coast marine climate is defined as having a mean annual temperature range of less than 36° F. (20° C.). Thus defined, the area here under consideration includes the British Isles, Belgium, Netherlands, Denmark, southern Sweden, western Norway, northwestern Spain, and almost all of France and Germany. The range is less than 20° along the coasts of these countries, but increases rather rapidly a short distance inland, chiefly because of higher summer temperatures. Throughout the region the winters are warm in relation to the average for the latitude. This positive anomaly is greatest in the British Isles and on the coast of Norway.

The usual rainfall regime of west coast climates in the belt of the prevailing westerlies has a winter maximum and a summer minimum. This is only partially true in western Europe. There is more rain during the winter half-year than during the summer half in the greater part of the British Isles and in a narrow coastal strip the entire length of the region from Spain to Norway. The interior portions, however, are sufficiently modified by continental influences to have most of their rain during the warmer half of the

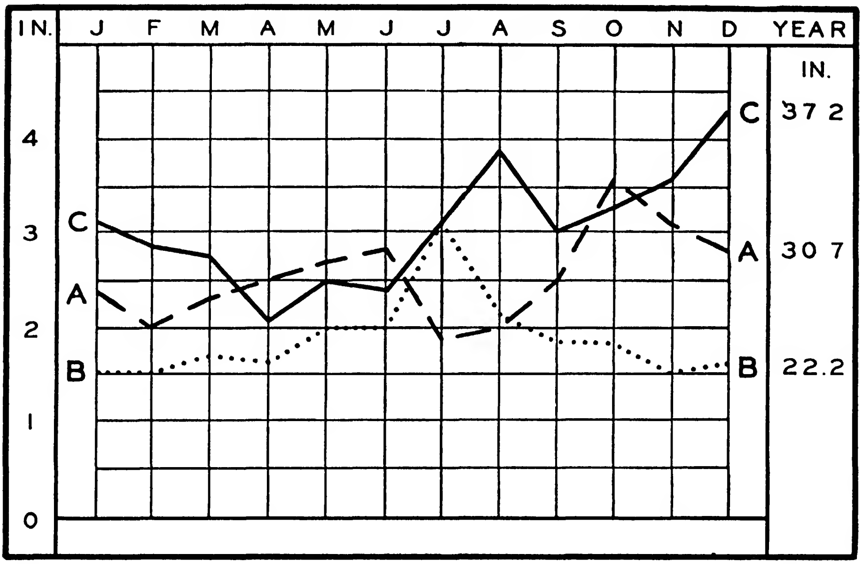

FIG. 88—Average Precipitation. Intermediate marine climate of western Europe. A. Bordeaux. B. Berlin. C. Glasgow.

year. In neither case, however, is the periodicity strongly marked; there is moderate rain in all months.

British Isles

These islands afford an excellent illustration of a markedly marine climate. The mean annual range of temperature is 15° to 25°. The mean daily range increases from 8° on the west coast to 12° or 14° in the interior and eastern portions. The temperature of the coldest month is 35° to 45° in spite of the high latitude. July mean temperatures are generally between 55° and 63°. Fluctuations in mean annual temperature from year to year are small —mostly less than 1°. Average cloudiness is six- to eight-tenths. The sun shines an average of only two and one-half to five and

one-half hours per day, 24% to 40% of the possible amount. Relative humidity is 79% to 80%. There are 150 to 250 rainy days a year.

> " Is not their climate foggy, raw, and dull,
> On whom, as in despite, the sun looks pale? "

Temperature. The western coasts of Great Britain and Ireland naturally show the greatest marine influence, and freezing temperatures are rare in these coasts. On some of the islands along the west coast the mean temperature of the coldest month is above 43°, and by this criterion the climate might be considered subtropical. On the other hand, the cool summers are very unlike the summer heat of regions in subtropical latitudes, and because of the low summer temperatures, the vegetation is quite different from that of the subtropics. Winter temperatures decrease inland from the western coast, but the coldest month averages above 35° everywhere except in the highlands. Summer temperatures increase from west to east, but are low throughout the islands. The highest July mean, about 63°, occurs in southeast England. Over middle and southeast England the maximum temperatures of record are mostly between 90° and 95°. In western England and in Scotland and Ireland the absolute maximum is between 80° and 90°. In most places the lowest temperatures of record are between 10° and 20°, but temperatures below zero have been recorded in the northern Midlands of England.

The coldest weather of winter and the warmest and driest weather of summer occur with northeast or east winds. These winds are frequent from March to June, and again in November. They bring continental air from the interior of Europe which is somewhat modified by its passage over the North Sea. In general, temperature conditions resemble those on the coast of British Columbia and southern Alaska. For example, London and Valencia correspond in latitude with Victoria, B. C., and both winter and summer temperatures are similar. In higher latitudes, Stornoway, Scotland, is 8° to 12° warmer in winter than are Sitka and Juneau, and it is slightly cooler in summer.

Rainfall. Because of the large number of barometric depressions crossing these islands there is much variability of wind direction, but the prevailing direction is westerly all year. These

depressions also result in frequent gales—winds of thirty-eight miles per hour or more. These average twenty to forty a year, mostly from a westerly direction. The lows are attended by rains that on the whole are well-distributed, seasonally and geographically. The changing direction of the wind with their passage produces rain whatever the direction of the slope. The rainfall is heaviest on the west coasts and on the western slopes of the mountain ranges, but the mountains are nowhere high enough or continuous enough to produce a serious rain shadow on their lee sides.

In England the annual rainfall varies from about twenty inches at a few places in the southeast to more than forty inches in a considerable area in the west. In Scotland the range is from twenty-six inches in some eastern areas to more than 100 inches in the west. Ireland has a little under thirty inches at places in the east, but more than sixty inches on the west coast. Local areas in the Welsh Mountains receive as much as 175 inches of rain in a year. The wettest month is December on the west coast of England and Ireland and in practically all of Scotland. In eastern England and eastern Ireland thunderstorms add to the summer and autumn rainfall, and the most rain occurs from August to October. The number of thunderstorms is not large, however, averaging five to ten a year over most of the region, but rising to twenty at places in eastern England. Spring is the driest part of the year because it is the season when the land is warmest relative to the sea, and also because it is the season when high pressure often develops north of the British Isles, causing easterly winds. Sunshine percentage is generally lowest in December and highest in spring.

The number of rainy days ranges from 150 in southeastern England to more than 250 in northwest England and in parts of Scotland, Ireland, and Wales. This is large in relation to the total rainfall, and, together with the high percentage of cloudiness, indicates the occurrence of much slow, continuous, light rain, characteristic of the warm front of a depression and of orographic rainfall. Amounts of one inch in twenty-four hours occur only three to five times a year. Fogs are a feature of the climate of the British Isles. They are mainly radiation fogs and occur most frequently in winter. The number of days with fog averages more than fifty a year in London and northward in eastern England, and more than forty over most of the area of the islands. These characteris-

IM *Climate of British Isles*	*Temperature, °F.*						*Precipitation (Inches)*			*Number of days*		*Rel. Hum., %*	
	Year	*Coolest month*	*Warmest month*	*Range*	*Highest*	*Lowest*	*Year*	*Wettest month*	*Driest month*	*Rain*	*Thunderstorms*	*Jan.*	*July*
England													
London	49.7	Jan. 38.9	July 62.7	23.8	94	9	24.5	Oct. 2 6	Apr. 1.5	167	14	85	73
Buxton	45.4	Jan. 35.3	July 57.4	22.1	89	−11	48.4	Dec. 5 7	Apr. 2.9	211	10	90	81
Scotland													
Aberdeen	46.3	Jan. 37.9	July 56.6	18 7	86	4	29.5	Dec. 3.2	June 1.7	214	6	80	78
Stornoway	46.0	Feb. 39.2	July 54.6	15.4	78	11	49.9	Dec. 6 3	June 2 3	263	3	91	88
Ireland													
Valencia	50.8	Feb. 44 3	Aug. 58.9	14.6	81	20	55.6	Dec. 6 6	May 3.2	252	7	86	84
Dublin	49.9	Jan. 42.1	July 60.1	18.0	87	13	27.4	Sept. 3 0	March 1.9	198	8	85	80

tics, together with the high average humidity and the absence of hot weather, make this a decidedly humid climate even where the annual rainfall is less than twenty-five inches. Abilene, Texas, in the sunny, semi-arid Great Plains, receives more rain per year than the moist and cloudy London, where the December sunshine averages only fifteen minutes a day. London has 23.8 inches of rain on 167 days a year; Abilene has 25.2 inches on sixty-seven days.

Crops. The crops and vegetation of the British Isles are such as are characteristic of cool, moist climates. Most of western and northern England is in grasses, more than half of the cultivated land of Ireland is in pasture, meadow, and clover, and one-fourth of Scotland is in permanent pasture. Large numbers of sheep and cattle are supported on these pasturelands. The principal cereal produced is oats, but of equal importance in the produce of the country are potatoes and the root crops, particularly turnips and rutabagas. On the southwest coasts laurel, myrtle, and other evergreen plants grow throughout the winter.

Northwestern Spain

The northern and northwestern maritime provinces of Spain, along the Bay of Biscay and the Atlantic Ocean, have a distinctly marine type of climate like that of the British Isles. The winter temperatures are no lower than those in parts of the Mediterranean climatic region to the south, but summer temperatures show a sharp contrast with the Mediterranean and steppe types that prevail in the remainder of Spain. They average 5° to 12° lower than in Portugal and southern Spain, but are somewhat higher than in similar situations in the British Isles. January temperatures at Oviedo and Santiago are about the same as at Valencia and the Scilly Islands, but August temperatures are 5° higher. In both regions August is somewhat warmer than July, as is frequent in marine situations.

The rainfall regime of northwestern Spain is similar to that of the west coasts of Great Britain and Ireland. The maximum is in autumn or winter and moderate amounts fall throughout the summer in contrast with the almost rainless summers of southern Spain. In the western part of the area the rainfall is heavy; at Santiago it amounts to sixty-five inches a year—ten inches more than falls at Valencia, Ireland. In the east the rainfall is moder-

ate, averaging about the same as the average for England, thirty-three inches. The mild winter temperatures and the infrequency of frosts permit the growth of cool weather plants all winter. Roses bloom in midwinter. In general, however, the vegetation is more like that of France and England than of southern Spain. The cool summers with adequate rainfall keep fields and meadows green and growing, presenting a marked contrast to the brown and parched fields of the Mediterranean lands. The mountain areas are forested with oak, beech, and chestnut.

France, Belgium, and the Netherlands

The coastal portions of these countries have an essentially marine climate similar to that of the British Isles. A short distance inland continental influences become apparent and increase slowly eastward, but the climate of Belgium, the Netherlands, and the greater part of France is distinctly of the west coast marine type (IM). The Mediterranean coast of France previously discussed, and the highlands of eastern France—Vosges and Jura Mountains—are exceptions. Winter temperatures are mild for the latitude, summer temperatures are moderate, and the annual range varies from about 25° to 33°. The rainfall averages about thirty-two inches in France, and twenty-eight to thirty inches in the Low Countries. There is much cloudiness, the humidity is high, and there are 150 to 200 rainy days. Much of the rain falls in continuous drizzle rather than in heavy showers. There are, however, fifteen to twenty-five thunderstorms per year. Snow is rare in southern France, but falls on fifteen to twenty days a year in northern France and in Belgium and the Netherlands. Winds are prevailingly from a westerly direction, but occasional east winds bring continental influences. These are most frequent in winter and in eastern France. The northern portions of the region are subject to frequent changes of weather, under the influence of the cyclonic depressions whose main path is across the British Isles and northern Europe.

Southwestern France. Southwestern France (see data for Bordeaux) has warm summers for a west coast marine climate. July and August mean temperatures of 68° equal the August mean at San Diego, and the mild winters approach those of the cooler portions of the Mediterranean type. Only two months have mean

temperatures less than 43°. Precipitation amounts to thirty inches a year, with a maximum in October and with a minimum in July and August, but with moderate amounts in all months. Wine grapes are the principal agricultural product; peaches, pears, and other fruits are grown, and there are also large acreages of cereals and vegetables.

Northwestern France. Northwestern France (see Nantes) is somewhat cooler than southwestern France during both winter and summer, but it has a smaller annual range. Because of the stronger and more strongly prevailing westerly winds in the higher latitude, the climate is more distinctly marine and is much like that of southern England. The rainfall is slightly greater than that in southwestern France. Much the same variety of climate prevails also in the north coastal regions and in the valley of the Seine, but the winters are somewhat cooler. Paris has three winter months with mean temperature below 40°, and an absolute minimum of —14° has been recorded. The highest temperature of record at Paris is 101°. The rainfall is light, 22.6 inches, average cloudiness is five- to seven-tenths, and there are 162 rainy days a year. These conditions are similar to those at London. Temperatures are also similar in the two cities. Paris is a little warmer in summer and cooler in winter than London, but there is only half a degree difference in the annual mean. Agriculturally these northern portions of France are largely devoted to pasturage, cereals, dairy-farming, and stock-raising. The extreme northeastern provinces have a large production of sugar beets.

Interior southeastern France. Lyon, at an elevation of 500 feet, representing the Rhone Valley and the southeastern interior of France, has summer temperatures equal to those of Bordeaux and winter temperatures 5° lower. The annual rainfall is about the same, but more of it falls in summer and less in winter. There are more heavy showers and fewer rainy days. In short the climate is less distinctly marine and more nearly continental. Similar conditions prevail in the central plateau region of France (see Clermont-Ferrand), except that the rainfall is about twenty-five inches instead of more than thirty inches. The Rhone Valley is a leading wine-producing region; stock-raising and dairy-farming are important industries in the central plateau.

Northeastern France. The coolest part of France is along the

IM *Climate of Western Europe*	*Elevation (Feet)*	*Mean Temperature, °F.*				*Av. Precipitation (Inches)*		
		Year	*Coolest month*	*Warmest month*	*Range*	*Year*	*Wettest month*	*Driest month*
England								
Oxford	208	49.0	Jan. 38.4	July 61.3	22.9	24.8	Oct. 2.9	March 1.6
Liverpool	200	49.0	Feb. 40.0	July 60.0	20.0	27.9	Oct. 3.3	Apr. 1.6
Scotland								
Glasgow	180	48.0	Jan. 39 0	July 59.0	20.0	37.2	Dec. 4.1	Apr. 2.1
Northwest Spain								
Santiago	886	54.9	Jan. 45.1	Aug. 66.0	20.9	65.2	Jan. 7.5	Aug. 1.9
France								
Bordeaux	33	54.1	Jan. 40.6	July 68.2	27.6	30.7	Oct. 3.6	July 1.9
Nantes	131	52 0	Jan. 39 9	July 64.8	24.9	30.9	Oct. 3 8	Aug. 1.8
Clermont-Ferrand	1280	50 4	Jan. 35.4	July 66.0	30.6	25.4	June 3.2	Feb. 1.3
Lyon	574	51 4	Jan. 35 1	July 68.2	33.1	31.3	Oct. 3.9	Jan. 1.5
Paris	164	50.3	Jan. 36 7	July 64.6	27.9	22.6	Oct. 2.3	Feb. 1.2
Belgium								
Brussels	328	48 2	Jan. 34 4	July 63.0	28.6	28 9	Aug. 3 0	Feb. 1.9
Netherlands								
Utrecht	43	48.0	Jan. 34.2	July 62.6	28.4	28.7	Aug. 3.3	Apr. 1.7
Denmark								
Copenhagen	16	45.9	Feb. 31.8	July 61.9	30.1	20.7	Aug. 2.6	Feb. 1.3
Southern Sweden								
Göteborg	33	45.0	Feb. 30.4	July 62.2	31.8	....	....	.....
Western Norway								
Bergen	66	44.6	Feb. 33.6	July 57.9	24.3	81.0	Oct. 8 9	June 3.8
Trondheim	33	40.5	Feb. 26.8	July 57.2	30.4	31.1	Oct. 3.4	May 1.5
Germany								
Munich	1740	46.2	Jan. 28.2	July 63.9	35.7	34.3	June 4.8	Feb. 1.3
Frankfurt-am-Main	341	49.3	Jan. 32.3	July 66.0	33.8	22.7	July 2.7	Apr. 1.2
Berlin	164	48.4	Jan. 31.5	July 65.8	34.3	22.2	July 3.1	Feb. 1.3
Hamburg	82	46.9	Jan. 32.5	July 63.0	30.5	27.5	July 3.5	Feb. 1.7
Stettin	100	46.9	Jan. 30.7	July 65.1	34.4	21.5	July 3.0	Feb. 1.2

east-central border in the Vosges and Jura Mountains. The plains to the west of these mountain ranges, at an elevation of approximately 500 feet, are represented by data for Strasbourg and Metz. The January mean temperature is below freezing and equal to the January mean at St. Louis, Missouri. There are five months when vegetative growth is stopped by mean temperatures below 43°. Summers are moderate, and the July mean is 13° less than at St. Louis. The maximum precipitation is in June and July, much of it in heavy showers often attended by thunder, but all months have between 1.5 and 2.75 inches. The climate is well-adapted to potatoes, and these are an important product of the region.

Belgium and the Netherlands. Belgium and the Netherlands are low, flat countries, and have a cool, equable marine climate with a mean annual temperature of 48° and with an annual range from 34° in January to 63° in July. Five months have a mean temperature below 43°. The summer temperatures are like those of London, but the winters are 5° colder, indicating more frequent easterly winds composed of cold, continental air. Contributing also to the colder winters is the presence of colder water in the North Sea than in the Atlantic west of the British Isles. The winter temperatures are like those of Port Simpson, British Columbia, of about the same latitude. A temperature of —9° has been recorded at Utrecht. Maximum summer temperatures frequently exceed 90°, but never reach 100°. The rainfall, twenty-eight to thirty inches a year, is well-distributed, but has a moderate maximum in August and a minimum from February to April. The August maximum, caused by heavier though less frequent showers than in winter, corresponds to the secondary maximum over much of the British Isles. Belgium and the Netherlands, like northern France, have a climate well adapted to pastures, cereal grains, and dairying. The Netherlands, especially, has a highly developed dairy industry.

Denmark, southern Sweden, and western Norway

The typical west coast marine climate, slightly modified by continental influences, prevails in these regions, which include all of Denmark, the southern peninsula of Sweden, and the coast of Norway, northward to latitude 64° N. North of this latitude tempera-

tures along the Norwegian coast become subpolar in character. The climate may be compared especially with that of the British Isles in the same latitudes. In both regions the mean annual temperatures are about 44° to 46°, but in the Scandinavian region the winters are several degrees colder and the summers warmer than in Great Britain. At Aberdeen, Scotland, the mean of the coldest month is 38°, and the warmest month 57°. At Copenhagen, Denmark, and Goteborg, southwestern Sweden, there are two winter months with means below 32° and two summer months above 60°. The annual ranges are 12° greater at Copenhagen and Goteborg than at Aberdeen. It is evident that continental effects are felt to a greater extent in these Scandinavian areas than in the British Isles. The west coast of Norway feels less of the continental influence than do Denmark and southern Sweden. At Bergen the annual range is 24°, and the winters are warmer than at Copenhagen, which is 5° of latitude farther south; but Bergen is 5° cooler in winter and 5° warmer in summer than Lerwick, Shetland Islands, where the annual range is only 4.5°. Farther north on the coast of Norway, the mean annual temperatures decrease to 40° at the northern limit of the type, and at Trondheim there are four months averaging below 32° and only four months above 50°.

As compared with an annual rainfall of thirty to fifty inches in Scotland, Denmark has twenty to twenty-eight inches, Sweden fifteen to thirty-five inches, and Norway fifteen to more than eighty inches. There is a maximum in August in all the more easterly, more continental situations, and in autumn or winter on the west coasts. In southern Sweden there is a marked decrease of rainfall from west to east. In the southwest, Borås has a yearly precipitation of 35.1 inches; in the southeast Kalmar has only 14.6 inches. Along the coast of Norway amounts are governed largely by exposure and topography, and are extremely variable. This coast has much cloudiness and is subject (mostly in winter) to stormy winds which attend the movement of cyclonic depressions.

The principal agricultural crops in all this region are oats, barley, and rye. Potatoes and other root crops are also produced. Meadows and pastures cover a large acreage, and dairying and cattle-raising are important industries. Beech and oak are prominent native trees in Denmark and southern Sweden, and ash, elm, and pine are abundant in the coastal area of Norway.

Germany

Most of the northern border of Germany is formed by the Baltic and the North Sea. The absence of high or continuous mountain systems leaves most of western Germany's border open to winds from the ocean. The prevailing winds throughout the country are westerly winds. For these reasons the northern and western portions of the country have a marine type of climate. The eastern portion, omitting the extreme northeast, has a transitional climate, showing marine influence but approaching the continental types found in eastern Europe. On the south, high mountain systems form an abrupt climatic divide with no transition zone. Germany has more cloudiness than does the Mediterranean region, but is subject to more clear, cold, easterly winds in winter than are the countries to the west.

Marine influence is most pronounced in the northwest. At Hamburg and Hanover the summers are cool and the winters mild, with no month below freezing. At Stettin, in the northeast, the winters are colder and the summers warmer. In this vicinity the Baltic harbors are frozen in winter, and help to keep the temperatures low. In summer the prevailing winds are southwest and are warmed in passing over the land. The most agreeable climate of Germany is that of the Rhine Valley (see data for Frankfurt-am-Main). Mild winters and warm summers make the Rhine Valley an important center of grape production and wine-making. Deciduous fruits, especially the apple, are also grown.

The interior of Germany has one or two winter months with mean temperatures below 32° and warm summers similar to those in the Rhine Valley. At Berlin the lowest temperature of record is —13° and the highest is 99°. Munich, Bavaria, at an elevation of 1,740 feet, is in the transition zone between marine and continental types of climate, and has three months below 32° and an annual range of 36°. The same is true of Breslau, Silesia.

The annual rainfall is between twenty and thirty inches throughout Germany (except in the more elevated regions), and is therefore rather inadequate for maximum crop production in the drier portions and during the drier years. It is rather well distributed seasonally, and no month averages less than one inch or more than four inches. The wettest month is usually July. Traveling depressions cross Germany in summer, giving cyclonic

rain, and convectional showers also contribute largely to the total. A summer maximum is a continental characteristic, but northern and western Germany show a marine effect by a secondary maximum in October. The winters are dry, for at that season high pressure overlies interior Europe and the cyclonic storms from the Atlantic take a more northerly course. February is the driest month. Except for occasional summer thundershowers, most of the rain falls slowly and in small daily amounts. At Berlin there are fifteen thunderstorms a year and 152 rainy days. Thus, with a total rainfall of 22.2 inches, the average amount per rainy day is only 0.15 inch. Berlin has thirty-four days with snow.

Cereals are produced throughout the country, wheat predominating in the south and west, and rye, oats, and barley predominating in the north and east. Potatoes, beets, hops, and tobacco are also grown. There are large areas in meadow and pasture, and stock-raising is an important industry. Oak and beech forests occur on the Baltic coast; elsewhere birches and conifers are most prevalent.

The Warm Humid Continental Climate of Central Europe (ICw)

The marine climatic type of western Europe merges on the east into the long summer, short winter continental type (ICw). The latter extends from east Prussia and Poland southward to northern Greece (Macedonia), and includes all of the interior countries of southeast Europe except portions of eastern Poland and eastern Rumania. It lies between latitudes 41° N. and 55° N. In southeastern Europe there are two rather extensive plains, known as the *Rumanian Plain* and the *Hungarian Plain,* both of which are tributary to the Danube River. For the rest, southeastern Europe, aside from the Mediterranean coastal plains, is a confused mass of hills and mountain ranges interspersed with small valleys and plateaus. For this reason it has many and large local variations in climate. North of the Carpathians is the undulating plain of the Vistula Basin in Poland and east Prussia, draining into the Baltic Sea.

These several regions comprise the warm, humid continental climatic province of central Europe. The same type in the United States includes the corn and winter wheat regions and the northern part of the cotton region. The European and American provinces

have approximately the same mean annual temperatures and much the same kind of vegetation and agricultural production; both provinces are centers of large production of corn and wheat. These grains are also important crops in the warm continental climate of north China. The general climatic conditions are similar in Europe, Asia, and America, but there are considerable differences in detail. It should be noted that the western European province is 500 or 600 miles farther north than the similar provinces in North America and Asia. In other words, for corresponding latitudes, this portion of Europe has a milder climate than eastern North America and eastern Asia, mainly because of its position in the western portion of a continent rather than in the eastern.

The summers are decidedly cooler in Europe than in the United States, and the winters are milder. There is a larger number of months in spring and autumn in which the mean temperature is above 32° but below 50°. That is, in spite of its more northerly latitude, the climate in the European region is less extreme and less continental than the corresponding climate in the United States. In America the coldest winters and hottest summers are found in the western portions of the region, but in Europe the continentality increases from west to east. In delimiting the types of continental climate in America, the warm type (ICw) had not more than three months below 32° and not less than six months above 50°, and the cold type (ICc) had more than three months below 32° and less than six above 50°. In central and southeastern Europe there is a large transition zone in which the winters conform to the definition of the warm type and the summers to the definition of the cold type. (For example, Vienna, Königsberg, Warsaw.) These transition zones may then be classed in either type, according to whether the winter conditions or the summer conditions are emphasized.

In Europe and America the rainfall has a maximum in summer, but in general there is not more than two or three inches' difference between the wettest and the driest months. This is in contrast with the rainfall regime of China, and also of Manchukuo, where the monsoonal influence is potent and where the rainfall is strongly concentrated during the three months of June, July, and August. The average rainfall is greater in the American area than in the European area, and increases from west to east, with increased in-

draft of warm, moist air from the Gulf of Mexico and the Atlantic Ocean. In Europe the amount decreases eastward toward the center of the continent with increasing distance from the ocean.

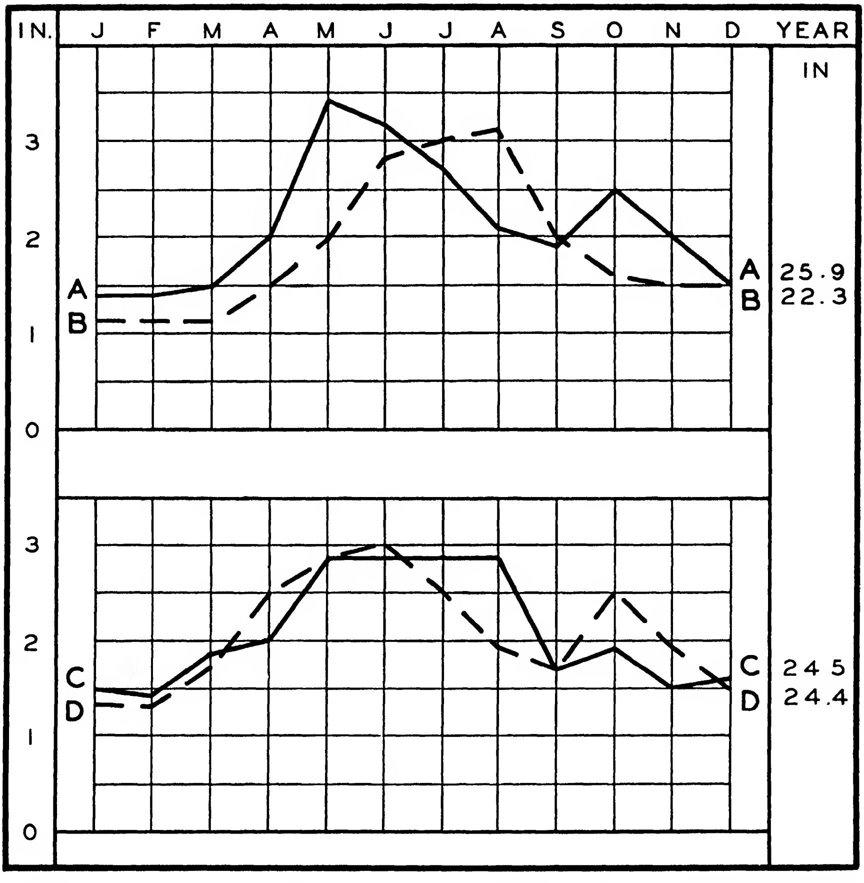

FIG. 89—Average Precipitation. Warm intermediate continental climate of central Europe.

A. Sofia, Bulgaria.
B. Warsaw, Poland.
C. Vienna, Austria.
D. Belgrade, Yugoslavia.

Albania and Macedonia

The coastal districts of Albania and Macedonia have a Mediterranean climate, but in the interior, which consists of complex mountain systems with intervening small valleys, the climate becomes continental in character, and has higher summer temperatures than on the coast and much lower winter temperatures. The January mean temperature falls from about 43° on the coasts to

32° or lower in some parts of the interior. These provinces, however, have mild types of intermediate climate with mean winter temperatures corresponding to those of Tennessee and Kentucky. The rainfall is about twenty-five inches a year, with a maximum in spring. Corn and small grains are the principal farm crops.

Bulgaria

The northern part of Bulgaria is in the Rumanian Plain; the southern part is mountainous and drains into the Aegean Sea. The northern plain is exposed to cold, continental winds from the north and has rather severe, though short, winters. It is subject to occasional cold waves during which the temperature falls as low as —20°, and January mean temperatures are below freezing. The higher tablelands are covered with snow in winter. The more mountainous southern district is sheltered from the northerly winds and has more moderate winters. The summers are moderately hot with frequent maxima between 90° and 100°. Rainfall averages about twenty-five inches, but varies much with exposure (Varna, eighteen inches; Sofia, twenty-six; Gabrovo, forty-two). Moderate amounts fall in all months. The wettest season is April to August, during which there are frequent thunderstorms. A secondary maximum occurs in October. Bulgaria produces grapes in considerable quantity, but cereals are the principal crop.

Yugoslavia (Croatia, Slavonia, Bosnia, Herzegovina, Montenegro, Servia)

The northern part of this district, bordering Hungary and Rumania, is a part of the lowlands of the Danube Basin. Most of the remainder is a chaotic group of mountain ranges with some fertile river valleys between the hills. The climate is marked by great local variability, but becomes rapidly more severe from south to north. Montenegro and Herzegovina are the mildest regions and some portions of these countries are subtropical in character, producing figs and citrus fruits. Other parts of Yugoslavia, especially where exposed to the north, are subject to frequent hard freezes and to outbreaks of high, cold NNE. winds (boras). January has an average temperature below 32° in these areas (Agram, Belgrade, Uskub). Belgrade has a mean annual temperature and a

ICw *Climate of Central Europe*	*Elevation (Feet)*	*Mean Temperature, °F.*				*Av. Precipitation (Inches)*		
		Year	*Coolest month*	*Warmest month*	*Range*	*Year*	*Wettest month*	*Driest month*
Macedonia								
Salonika	80	60.6	Jan. 41.7	July 79.9	38 2	21.5	Nov. 2.7	July 1.0
Bulgaria								
Sofia	1800	50.0	Jan. 28.9	July 68.7	39.8	25.9	May 3.4	Feb. 1.4
Yugoslavia								
Agram	500	51.6	Jan. 30.9	July 70.9	40.0	35.1	Oct. 4.2	Feb. 1.7
Belgrade	460	52.2	Jan. 30.4	July 71.2	40.8	24.4	June 3.0	Feb. 1.2
Uskub	800	53.2	Jan. 29.5	July 73.8	44.3	20.1	May 2.2	March 0.8
Austria								
Vienna	660	48.6	Jan. 28.9	July 67.3	38.4	24.5	June 2.8	Feb. 1.3
Hungary								
Budapest	500	49.8	Jan. 28.2	July 70.3	42.1	25 9	June 3 0	Feb. 1.3
Debreccn	450	49.3	Jan. 25.2	July 70.9	45.7	24.5	June 3.1	Feb. 1.1
Rumania								
Bucharest	280	51.1	Jan. 26.2	July 72.3	46.1	23.1	June 3 5	Feb. 1.1
Sulina	10	52.0	Jan. 30.6	July 72.1	41.5	15.4	June 1.9	Feb. 0.8
Bohemia								
Prague	....	48.1	Jan. 29.7	July 66.2	36.5	19.3	June 2.8	Feb. 0.8
Poland								
Warsaw	440	45.6	Jan. 25.9	July 64.8	38.9	22.3	Aug. 3.1	Feb. 1.1
East Prussia								
Königsberg	16	44.6	Jan. 27.0	July 63.3	36.3	20.5	Aug. 2.7	March 1.0

mean winter temperature like those of Pittsburgh, but the springs are warmer and the summers are cooler at Belgrade. Also, Belgrade's rainfall is twelve inches less than Pittsburgh's.

Parts of Yugoslavia are subject, too, to the warm, moist sirocco from the southwest, which often brings rain to the southern slopes.

The rainfall approaches the subtropical regime, with a maximum in winter and with dry summers. The summers are hot, and maximum temperatures are often above 100°. Sugar beets, rice, and tobacco are grown in addition to corn and winter wheat, and there are large areas of mountain pastures.

Austria

Although northern Austria is in the Danube Basin, it is hilly, and less than half of the area is arable; southern Austria is mountainous and has only about 10% of its land under cultivation. Forests cover 30% to 50% of the country. The average temperature is below 32° for two months and, in the colder districts, for three months. Occasional invasions of cold air are attended by subzero temperatures. The summers are moderate, the hottest month averaging below 70°, and the highest temperature occurring in the average summer is between 90° and 95°. Only five or six months have means above 50°.

Vienna, which is farther north than Minneapolis or Quebec, has a mean winter temperature like that at Kansas City, a summer mean a half degree warmer than Winnipeg, and an annual mean like that of northern Iowa. The annual range at Vienna is 38°, as compared with 50° at Kansas City and with 59° at Minneapolis and Quebec. Austria's continentality, then, is decidedly less than that of interior North America, and the influence of the warm westerlies from the Atlantic is evident as far inland as Vienna. Rainfall is moderate, about twenty-five inches a year, except under local orographic influences. The wettest months are May to August, but there is much clear weather during these months and cloudiness is less in summer than in winter. There is no distinct dry season. Some cereals and some grapes are produced in Austria, but forestry, cattle-breeding, and dairy-farming are the principal agricultural pursuits.

Hungary

Hungary consists of an extensive central plain surrounded by high mountains. The climate is more continental than that of Austria. There are three months with mean temperatures well below freezing, and there are seven months above 50°. The July average is about 70°. The annual range of temperature is 42° to 46°. The temperatures are similar to those in that part of western

New York which is subject to some influence from the Great Lakes, and which, like western Hungary, grows hardy varieties of grapes. The winters and springs are somewhat warmer in Hungary than in western New York; the summers, however, are about the same, and the autumns are slightly cooler. (Compare Budapest and Debrecen with Rochester and Buffalo.) Rainfall in the Hungarian Plain is about twenty-five inches yearly, as in Austria. It is heaviest in the summer months, but there is a distinct secondary maximum in October. The summer rains are largely convective, and are uncertain. There are occasional violent showers which cause floods, and, on the other hand, there are occasional long dry periods which are damaging to crops. Wheat, corn, and potatoes are important crops, and wine production is extensive.

Rumania

As the continentality of the climate continues to increase eastward, Transylvania and northern Bessarabia have colder winters and hotter summers than has Hungary. Temperatures fall as low as —20°, and summer temperatures above 100° occur. The cold winters are due to the prevalence of northeast winds from Russia for about five months. In summer, both northerly and southerly winds are hot. Walachia, which is in the Danube Valley and which is protected on the north by the Transylvanian Alps, has a climate like that of Hungary, with three cold months and with seven months above 50°. (See Bucharest.) Southern Bessarabia belongs climatically in the Ukrainian steppe region (type IS). Dobruja, too, approaches steppe conditions. (See Sulina.) Rainfall varies from about fifteen inches a year in this steppe region to between twenty-five and thirty inches over most of the remainder of Rumania. The greater part of the rainfall occurs during the growing season. The Rumanian Plain is one of the most important corn and wheat regions of the world. Other crops produced are wine grapes, potatoes, beets, tobacco, and the common fruits of middle latitudes.

Czechoslovakia (Bohemia, Moravia, Slovakia, Ruthenia)

Bohemia is an undulating plain, surrounded on north, south, and west by mountain ranges. It has a mild continental climate, transitional between the marine climate of eastern Germany and the more severe climates farther east. Prague is 2° of latitude

north of Vienna and its summers are cooler than the Vienna summers; the winters, however, are somewhat warmer than those at Vienna, and the annual range is only 36.5°. Prague has a recorded maximum temperature of 98° and a recorded minimum of —13°, but during the average winter the temperature does not fall to zero. Moravia and Slovakia constitute a mountainous plateau region with much local variation in climate, but on the whole they are more continental in character than is Bohemia. In particular, the northern portions, which are the higher portions, have more rigorous winters. Ruthenia has a similar climate, for though farther east, it is better protected from the severity of the Russian climate by the Carpathian Mountains. The Bohemian Plain has an annual rainfall of only eighteen to twenty inches, 70% of which falls in the summer half-year. The amount is somewhat greater in the plateaus, and rises to forty inches and more in the mountain areas. The principal products of the soil are corn, oats, barley, potatoes, and beets.

Vistula Basin and the Upper Dniester (Poland and East Prussia)

This region extends from the Baltic Sea to the Carpathian Mountains, mostly as a rolling plain, but rising in a series of plateaus as the mountains are approached. The prevailing winds are westerly, and the climate shows a considerable marine influence, particularly in the north. Königsberg has an annual temperature range of only 36.3°. The range increases to 39° at Warsaw and to 42° at Lemberg (Lwow). The mean annual temperatures are about the same in the north and in the south and average 44° to 46°, which is 2° to 4° lower than in corresponding latitudes in east Germany and in Bohemia. The mean temperature of the three winter months is 25° to 28°. The temperature may be expected to fall slightly below zero about half the winters. A minimum of —22° has been recorded at Warsaw. The rivers of the region are frozen for two or three months. The winters are similar to those of southern Iowa, but the summers are 10° cooler, and the highest temperature during the summer is usually about 90°. The rainfall is only twenty to twenty-four inches, and the wettest months are June to September. The principal crops are wheat, rye, oats, and potatoes. The summers are too cool for extensive production of corn.

The Cold Humid Continental Climate of Northern Europe (ICc)

This short summer, long winter type includes a small portion of Norway and Sweden from Oslo to Stockholm, and extends from the Baltic Sea eastward across central Russia to the Ural Mountains and then in a narrowing belt into Siberia to about longitude 90° E. On the west it includes Estonia, Latvia, Lithuania and eastern Poland. This type, as it occurs in North America and Manchukuo, has already been discussed. In North America the region is often called the *spring wheat and pasture region,* and it extends from the Dakotas and the Prairie Provinces of Canada eastward to the New England states and the St. Lawrence Valley. The typical temperature limitations of the type are four or five months with mean temperatures below 32°, and also four or five months with means above 50°. This European region consists of great plains and flatlands of remarkable uniformity which lie roughly between latitudes 50° and 60° N. This is considerably farther north than the corresponding zones in eastern Asia and in North America. (There are no similar climates in the Southern Hemisphere.) Thus, the Baltic region and central Russia, although they have long and severe winters, are relatively warm as compared with other extensive land areas in the same latitude.

The reasons for the existence of an intermediate type of climate in latitudes where in other regions subpolar conditions are found are, first, that the prevailing winds are westerly and from an abnormally warm water surface, and, second, that the prevailing flatness of the terrain permits these winds to move far inland. Thus, although the climate is definitely continental, it is not subject to the complete domination by continental influences that is found in the eastern portions of continents. In winter the region lies between the western side of the great Siberian High and the eastern side of the North Atlantic Low, and hence the normal flow of air is from the southwest. In summer the ridge of high pressure from the Azores to the Baltic region results in winds that are prevailingly northwest.

These prevailing winds are frequently interrupted by the shifting winds which attend the movement of the warm and cold fronts of cyclonic depressions. These depressions are most numerous in winter, and their centers usually move across Scandinavia and

northwestern Russia. Hence central Russia is often in the warm sector of such storms, and therefore the severity of the winters is somewhat mitigated. Light snows usually occur with the passage of these depressions. In summer, although the main track of the cyclones is farther north, a number do move inland from the Baltic Sea across central Russia. These are chiefly responsible for the summer rains in this region, and are frequently attended by thunderstorms. The average wind movement is rather high across these unbroken plains, especially in winter, when there are occasional violent winds attended by blowing, drifting snow (burans or blizzards).

Temperature

The mean annual temperatures of this region vary from about 44° in the southwest to 32° in the Siberian portion of the region. The January means range from 25° on the Baltic coast to —5° in western Siberia, and the July means are mostly from 62° to 70°. The annual ranges of temperature are less than 40° on the Baltic coast, but they increase eastward, exceeding 70° at the eastern extremity of the zone. Even when the Baltic Sea is frozen, it still has an ameliorating effect upon the temperatures. This is shown by the fact that the winter isotherms trend almost north and south; they are governed more by distance from the sea than by latitude. In summer, when the winds are lighter and when the sun is above the horizon for seventeen to nineteen hours, the temperatures are more directly responsive to surface heating, and the isotherms approximately follow the parallels of latitude.

In Fig. 90 a comparison is made between the annual march of temperature of Kazan (latitude 56° N., longitude 49° E.) and that in similar climates in Manchuria and in North America. Kazan is 10° of latitude north of Harbin, but has the same mean annual temperature, 37.9°. Kazan is 6° N. of Winnipeg, but more than 3° warmer. The annual march is much the same at the four stations. Note the rapid rise in spring and the almost equally rapid descent in autumn. At Kazan May is 34° warmer than March, and November is 28° colder than September. Between these periods of rapid change there is a brief summer, when mean temperatures range between 62° and 72°. Only these three months are entirely free from frost. The greatest differences among the four stations occur during the winter months. On the whole the tem-

perature conditions at the two Eurasian stations are intermediate between those at Minneapolis and Winnipeg.

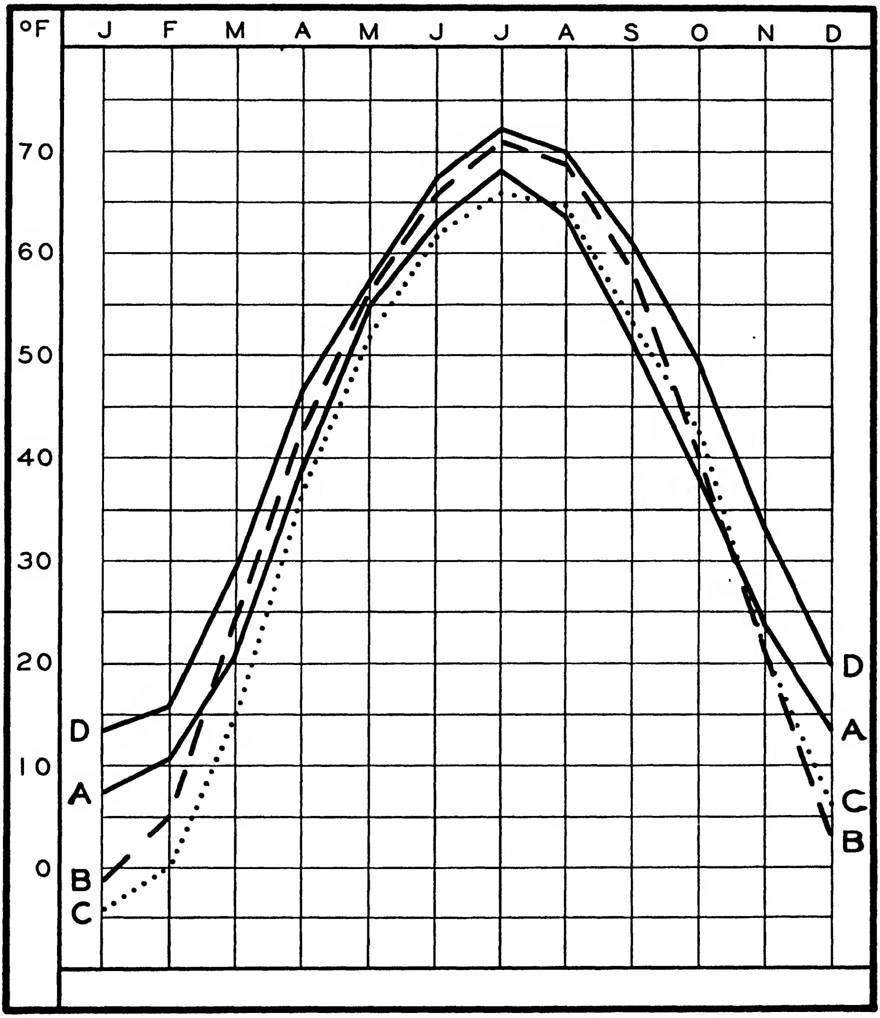

FIG. 90—Average Temperature. A comparison of the cold intermediate continental climates of Russia, Manchuria, and North America.

A. Kazan (Lat. 56° N.). C. Winnipeg (Lat. 50° N.).
B. Harbin (Lat. 46° N.) D. Minneapolis (Lat. 45° N.).

Rainfall

The rainfall in the central Russian region occurs in connection with traveling depressions, and amounts to about fourteen to

twenty-four inches per year. In general it is greatest near the Baltic Sea, and it decreases, though irregularly, eastward and southward. On the south the climatic province merges into the steppe region that extends eastward from Ukrainia, but the rainfall is favorably distributed through the year for agricultural purposes, the maximum occurring during the short warm season of long days and rapid growth in June, July, and August. The rainfall during the summer months occurs mostly in small daily amounts; there are, however, some heavy showers. There are ten to twenty thunderstorms during this period. During the remainder of the year most of the precipitation occurs in numerous light snow storms. The number of rainy days a year, averaging as many as 150 days, is therefore large in relation to the total fall.

Because of the small annual evaporation, the light rainfall is sufficient in general to maintain soil moisture, but south of latitude 55° N. there are occasional years of drought and resulting crop failure and famine. This southern area is a prairie, interspersed with forests—mostly of oak—and has a fertile black-earth soil. It is one of the major wheat-producing regions of the world. Rye, oats, and other cereals are also grown. Between latitudes 55° and 60° N. there are extensive and dense coniferous forests which merge into the taiga on the north. There are also open prairie regions, however, in which rye and oats are the leading crops, and some barley, wheat, and flax are grown, too. As in other regions of this climatic type, the shortness of the growing season limits large-scale production to such quick-maturing crops as the cereals, and, in the case of Manchukuo, soybeans.

The Subpolar and Polar Climates of Eurasia

Stretching across northern Eurasia from the Scandinavian Peninsula to the Bering Sea is a vast region having a subpolar climate (SPT) characterized by long and severe winters and by a short warm season with one to three months averaging warmer than 50°. In Europe it lies roughly between 60° N. and the Arctic Circle ($66\frac{1}{2}$° N.); in Siberia it broadens out, and in places extends from 50° N. to 70° N. For the most part it consists of vast plains and tablelands of remarkably uniform topography. This great tableland is interrupted by the Ural Mountains, which separate

Europe from Asia, and by a series of ridges and low mountain chains in the immense plateau which constitutes the eastern half of Siberia. The region is largely and typically covered with dense coniferous forests to which the Russians applied the name *taiga.* The word is now used as the name of the climatic type (SPT) as it occurs both in Eurasia and in North America. In the southern portion of the region the conifers, chiefly spruce, fir, larch, and pine, are mixed with deciduous hardwoods, birch, oak, maple, and elm. On the borders of the steppe regions to the south the forests are separated by open prairies.

Toward the northern border of the taiga the size of the trees declines, and they become mere shrubs and bushes as the taiga merges into the tundra. The tundra (PT) is the polar climatic type prevailing in the frozen lowlands bordering the Arctic Sea; in the tundra the mean monthly temperatures are below 50° throughout the year, but they are above 32° for one or more months. The typical tundra has no trees, but has a continuous cover of mosses, sedges, and lichens. The Eurasian tundra comprises the Arctic coastal plain from extreme northern Norway and northern Finland to Bering Strait, and the Bering Sea coastal region southward to latitude 60° N.

Norway, Sweden, and Finland

Most of Norway, Sweden, and Finland north of latitude 60° N. is included in the taiga climatic region, but the climate in these countries is subject to considerable marine influence and is not as severe as it is farther east in the same latitudes. A large part of this area consists of hills and plateaus, and there are, accordingly, marked local variations in climate. Most of the region, however, has a mean annual temperature ranging from 32° to 38°, and three summer months above 50°. The winters are long (six months average below 32°), but, because of the prevalence of westerly winds and the absence of much influence from the center of the continent, they are not particularly severe for the latitude. For example, Haparanda, at the head of the Gulf of Bothnia, latitude 66° N., has a longer winter than Bismarck, North Dakota (latitude 40° N.), but the coldest month averages 10.6° at Haparanda and 7.8° at Bismarck. The Bismarck summer is two months longer, and June, July, and August average 10° warmer than at

Haparanda, even though in June the sun is above the horizon for twenty-three hours a day at Haparanda.

The average rainfall of the region is about nineteen or twenty inches, decreasing from more than twenty-five inches at places in the southern interior of Norway and Sweden and along the northern coast of Norway to about thirteen inches in the northern interior. The heaviest rain occurs in late summer. In most places August is the wettest month, but in some areas September is wettest. The rainfall is lightest from February to April. The ground is snow-covered from November to February or March, and, in Finland, even into April. Crops are often destroyed by late frosts, and light frosts may occur in mid-summer.

The greater part of the area is covered with forests of the mixed conifer and hardwood type, and lumbering is a leading industry. Agriculture and dairy-farming are of importance, however, in the southern part of the region, the principal crops being rye and barley. These cereals are grown in limited areas as far north as the Arctic Circle. The northern part of Finland is a dreary, sparsely inhabited region of hills and plateaus. The Gulf of Bothnia is ice-bound and closed to navigation for about six months, November to May.

The Russian-Siberian taiga

The great forested plains that constitute the Russian-Siberian taiga stretch across northern Eurasia through 140° of longitude—almost two-fifths of the distance around the globe. They are a vast, thinly inhabited region, and because of the shortness and coolness of the summers they form a border zone for agricultural pursuits. The presence of this great continental land mass in high latitudes results in the most extreme of continental climates. The winters are long and extreme, but as the insolation received changes from zero in winter to a summer amount greater than that received at the equator in an equal period of time, there is a rapid rise to a surprisingly warm, though brief, summer.

The cooling of the continental interior in winter results in the development of a great area of high pressure which covers most of Siberia, and which not only dominates Siberia's winter climate but that of most of the rest of Asia. The heating of the interior during the summer months results in the development of a similarly ex-

tensive area of low pressure and the consequent inflow of some moist and warm air from a southerly direction. In the European taiga the pressure distribution produces some southerly and westerly winds during both winter and summer, and the climate is less extreme. Much the greatest portion of the Eurasian taiga climatic province is the Siberian portion, and it is in Siberia that the characteristics are most strongly developed. This Asiatic region will be discussed first, and the European modification will be noted later.

SPT *Climate of Eurasia*	*Elevation (Feet)*	*Mean Temperature, °F.*				*Av. Precipitation (Inches)*		
		Year	*Coolest month*	*Warmest month*	*Range*	*Year*	*Wettest month*	*Driest month*
Haparanda	33	32.5	Feb. 10.6	July 59.0	48.4	....	...	.
Archangel	50	32.2	Jan. 8.1	July 59.5	51.4	16.8	Aug. 2 4	Feb. 0.7
Ust Zylma	80	27.7	Jan. −0.9	July 57.9	58.8	16.6	July 2 6	Apr. 0.6
Tobolsk	340	31.5	Jan. −2.7	July 64.0	66.7	18.6	July 3.5	Feb. 0.6
Tomsk	400	30.6	Jan. −2.9	July 64.0	66.9	19.9	July 3.0	Apr. 0.7
Chita	2230	26.6	Jan. −17 0	July 65.8	82.8	....	.....	. ..
Yakutsk	330	13.3	Jan. −46.3	July 66.2	112.5	13.7	Aug. 2.6	Feb. 0.2
Verkhoyansk	360	3.0	Jan. −58.2	July 59.2	117.4	3.9	July 1.2	March 0.0

Siberia

The development of the great Siberian anticyclone during the winter months leads to light winds and clear skies, and this, together with the small moisture content of the air, facilitates further rapid cooling. By this process, interior northeast Siberia, where the winds around the High are northerly, becomes the coldest inhabited portion of the globe. The record at Verkhoyansk, just north of the Arctic Circle, at longitude 133° E., has long made

it known as the "cold pole" of the earth. This station has a record low temperature of —94°; the average minimum in January is about —80°, and the average temperature of January is —58°. These temperatures are endurable only because the air is quiet and very dry. Verkhoyansk has five months (November to March) of mean temperatures more than 20° below zero. Yakutsk, at latitude 62° N., is only less extreme, having a January mean of —46° and five months with mean temperatures of —8° or colder. Chita (Tchita), in approximately the latitude of London, Berlin, and Winnipeg, has a January temperature 56° colder than London, 48° colder than Berlin, and 13° colder than Winnipeg.

With the return of the sun an exceptionally rapid rise in temperature occurs; at Verkhoyansk June is actually 76° warmer than March. There follows the three-month summer, and July temperatures reach mean values of 60° to 65° over a greater part of the Siberian taiga; afternoon maximum temperatures are above 80°. Verkhoyansk has a recorded maximum of 94°, and thus has an absolute range of 188°—from 94° to —94°—the greatest of record anywhere in the world. This station's mean annual range of 117°, from —58° in January to 59° in July, is also a world record. The annual range is extreme, above 70°, throughout the Siberian taiga except in its southwestern portion. In that portion (see the records for Tomsk and Tobolsk) the winters are less severe because the area is on the western side of the center of high pressure and has southerly winds in winter; only January has a mean temperature below zero. After the brief summer of the taiga the temperatures decline with extraordinary rapidity. There is a fall of 40° from October to November at Verkhoyansk and a fall of 85° in three months. At Yakutsk the fall is 36° in one month and 76° in three months.

In northeastern Siberia the precipitation is extremely light. It averages about five inches a year or less. This is the region of light, northwesterly winds and of descending and warming air on the northeasterly side of the winter high. Only in July and August, when there is some monsoonal influx of moist air and some thermal convection, does the rainfall rise to as much as one inch a month. In the remainder of the taiga both in Asia and in Europe the rainfall amounts to from fourteen to twenty inches a year, with the greatest amounts always in the summer months from June to

September. Winter precipitation is light everywhere, and over most of Siberia there is no large accumulation of snow. The burans cause much drifting of the hard, dry snow, accumulating deep drifts in places and leaving large areas bare. In spite of the light rainfall the taiga is largely a region of marshy land and water-logged soil. This is because of the small evaporation and the permanently frozen subsoil which prevents percolation. Only the upper few feet thaw during the summer. Thus, ten to twenty inches of rain in this region are more effective in keeping the earth's surface wet than are the heavy rains of tropical regions. Fifteen inches of rain in Siberia are equivalent to 100 inches in the Amazon Basin.

European taiga

In the European portion of the taiga and in extreme western Siberia the winters are subject to more inflow of southerly and westerly air from warmer regions, and they are therefore less severe than the winters just described. They are also less severe than those in similar latitudes in the Mackenzie Valley and interior Alaska in the Western Hemisphere. Ust Zylma, near the Arctic Circle (latitude $65\frac{1}{2}°$ N., longitude 52° E.), has only January with a mean temperature below zero, but, like Verkhoyansk, it has seven months below freezing. The summer months are not quite so warm as at Verkhoyansk. Archangel on the White Sea is subject to considerable marine influence and has a climate like that of Finland and northern Sweden, with six monthly means below freezing but with none below zero. Its January mean is like that of Bismarck, North Dakota, and its July mean is slightly higher than that of San Francisco. In this western part of the Russian taiga the mean annual temperature is slightly above 32°, and hence the ground is not permanently frozen. In the warmer portions of the taiga there are tracts of arable land among the forests and marshes, but the soil is shallow and poor. Rye is the principal crop, for both climate and soil are unsuited to wheat. Agriculture is of minor importance, however. The main resources of the taiga are its lumber, minerals, furs, and fishes.

The Eurasian tundra

Along the Arctic Ocean north of the taiga stretches the tundra from Finland to the Bering Sea. This consists of barren coastal

plains, which are totally devoid of trees and which have a truly polar climate (PT). No month has a mean temperature as high as 50°, but one or more months do exceed 32°, and hence there is some surface thawing. Where the taiga merges into the tundra and at least one month approaches a mean temperature of 50°, there are low bushes, creeping trees, and dwarf birches a few inches high. These give way to areas where the only vegetation consists of mosses and lichens, and these in turn give way to wholly barren, rocky ground known as the *desert tundra.* The vegetative cover exists where the mean temperature of the warmest month is between 43° and 50°. Where the average daily temperature is continuously below 43°, there is only the desert tundra. The winters in the tundra are not as severe as they are in the taiga of the Lena River region of northeastern Siberia. The surface of the Arctic Ocean, even though it is completely frozen over for six months of the year, does not become as cold as the land surface because there is more conduction of heat from the unfrozen water beneath the ice than from the frozen land.

It is not, therefore, the severity of the winter that renders the region of little value and makes it almost uninhabitable, but the absence of a summer. There are practically no permanent inhabitants in the tundra, because of the lack of resources by which they could live. During the warmer part of the year, however, hunters, fishers, and reindeer-breeders of the native Siberian tribes do enter the tundra. The precipitation, although amounting to only eight to ten inches a year, is sufficient under the prevailing temperatures to maintain a marshy condition over much of the area.

CHAPTER XXI

Tropical Climates of Africa

Africa, like South America, is a warm continent, and much the greater part of its area lies within the tropics. Unlike South America, it extends almost equal distances north and south of the equator, but its greatest area is in the Northern Hemisphere. It reaches a short distance outside of the Tropics in both hemispheres. Its most northerly point, in Tunisia, has approximately the latitude of Richmond, Va., and its most southerly point, Cape Agulhas, is about the same distance from the equator as is Cape Lookout, North Carolina. Unlike the three other major continents, Africa has no extensive lofty mountain system. On the other hand, it has a comparatively small area of lowland. A large part of the continent consists of plateaus at elevations of 3,000 to 6,000 feet.

In the northwest the short Atlas Range separates the coastal plains from the interior desert. Inland from the Gulf of Guinea there is the small mountainous region of the Cameroons. On the east, high plateaus extend from Ethiopia to the Union of South Africa, rising in isolated areas to the height of mountains. The highest and most extensive of these mountain areas are the Abyssinian highlands and the long narrow ranges in Kenya and Tanganyika Territory which have rift valleys between them. There are four interior lowland areas of moderate size. These are in the Lake Chad Basin and in the basins of the Congo, the Niger, and the White Nile. In the Sahara there are small depressions even below sea level, and there are also isolated hilly regions. For the rest Africa is a series of plateaus which extend to the sea and there descend steeply. Hence there are no coastal lowlands of much width, except at the mouths of rivers that have cut valleys through the escarpments.

The presence of these great expanses of tropical highlands is a fortunate climatic circumstance, for they have a pleasant and healthful climate where otherwise there would be the enervating, depressing climate of equatorial lowlands. The tropical rainy

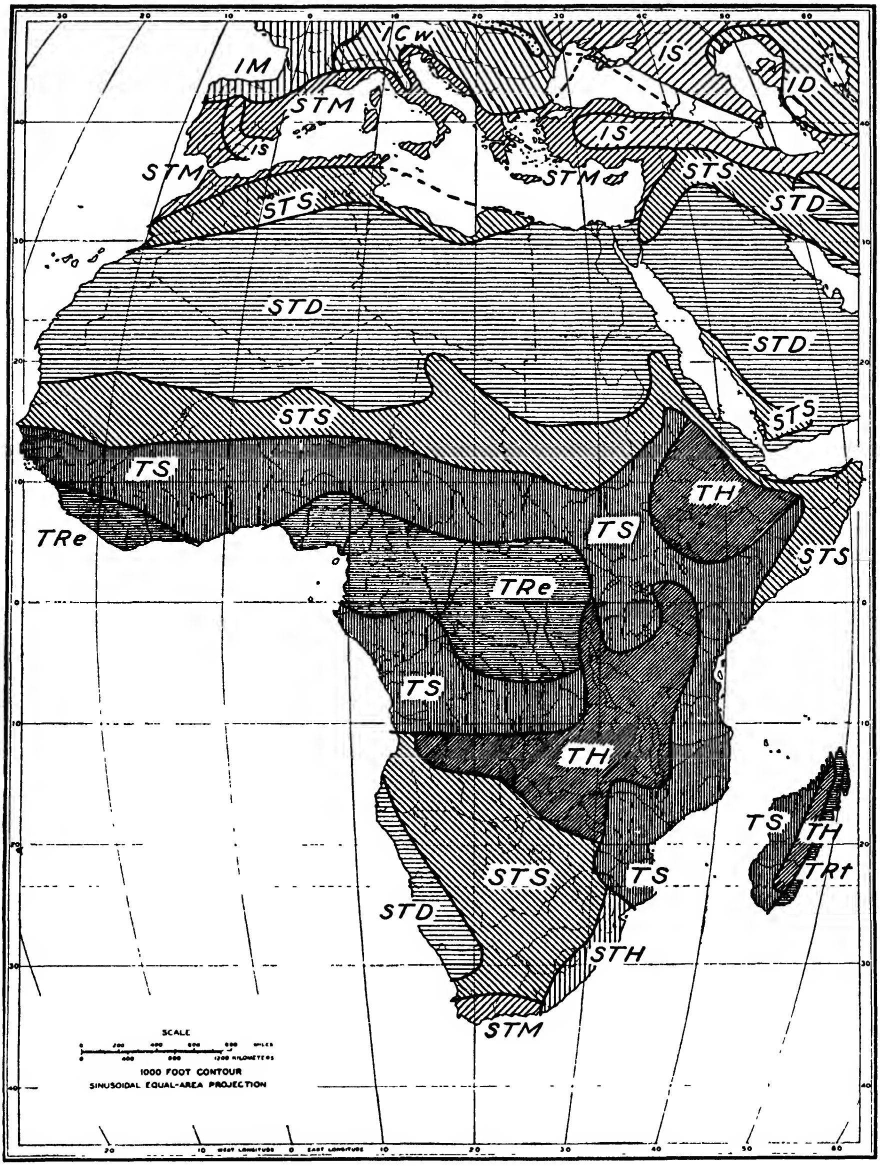

FIG. 91—Climates of Africa.

TRe—Tropical Rainy (equatorial subtype).
TRt—Tropical Rainy (trade wind subtype).
TS—Tropical Savanna.
TH—Tropical Highland.
STS—Low Latitude Steppe.
STD—Low Latitude Desert.
STH—Humid Subtropical.
STM—Mediterranean.
IS—Middle Latitude Steppe.
ID—Middle Latitude Desert.
IM—Humid Marine.
ICw—Humid Continental (warm subtype).

and savanna types of climate occupy considerably less area in Africa than in South America, and the tropical highland type occupies a much greater area. On the other hand, Africa is climatically unfortunate in that it has a broad area, 3,500 miles long, in the northern trade wind belt. The trade winds are normally dry as they move toward the equator, and in this case they are drier than elsewhere because they are continental winds from the dry interior of Eurasia. In consequence Africa has the most extensive desert area of the globe.

The Mediterranean coastal region of Africa is within a belt of shifting winds. It has northerly to northeasterly trade winds in summer, when the subtropical ridge of high pressure lies over Europe and when the trade winds are farthest north. In winter the ridge of high pressure extends into northern Africa, and pressure is low over the relatively warm waters of the Mediterranean; hence, westerly winds prevail on the North African coast. The climate of the western part of this coast has been described in connection with the Mediterranean Region. In the eastern part steppe and desert conditions extend to the coast. Southward from this coastal region to about 18° North latitude is the vast Sahara Desert in which the dry northeast trades prevail during the whole year, blowing into the equatorial belt of low pressure. In July the center of this belt across Africa is at about 18° North latitude. In January, it migrates slightly south of the equator over the interior of Africa. Hence the area between the equator and 18° N. is also a region of shifting winds. This is the region of the Sudan and northern Equatorial Africa. It has northeast winds in winter, when the low is south of the equator, and south to southwest winds in summer, when the low is far to the north. These latter are the southeast trades that have crossed the equator and have been deflected to the right. In this belt of shifting winds the rainfall also follows the sun. The maximum rainfall occurs at the season when the sun is overhead.

In the Southern Hemisphere, the subtropical belt of high pressure crosses extreme southern Africa throughout the year, and the equatorial low is never much south of the equator. Thus, in southern Africa, winds are predominantly from a southerly direction all year, except that the northeast monsoon of the northern winter extends southward along the east coast of Africa to about 15° South latitude. South of this latitude the southeast trades predominate in eastern Africa. In western Africa south of the equator

the winds are southwesterly all year because they are deflected toward the low pressure in the interior.

It will be observed that Africa is essentially an equatorial and trade wind continent. For this reason it has no traveling cyclonic depressions such as are characteristic of middle latitudes. The continent is also free from violent tropical cyclones (hurricanes), but these sometimes occur on the east coast of the Island of Madagascar. It does have violent thunderstorms and severe dust storms, and the equatorial lowlands have incipient tropical cyclones with heavy and prolonged rain, but generally without destructive winds. Africa is the warmest of the continents and has no cold climates.

The Tropical Rainy Climate of Africa (TRe)

A tropical rainy climate of equatorial subtype (TRe) prevails in much of the Congo Basin and in the narrow strip along the upper Guinea coast. In this coastal region of west Africa between the equator and 10° North latitude the tropical rainy climate is exemplified at its worst. The constant moist heat is oppressive and unfavorable for habitation by white people. The same type of climate, but with a somewhat lower average temperature and humidity, extends inland across the middle and upper Congo Basin to the highlands at about longitude 30° East, including a middle portion of French Equatorial Africa and the northern two-thirds of the Belgian Congo.

Temperature

The temperature of these regions is typically tropical in its

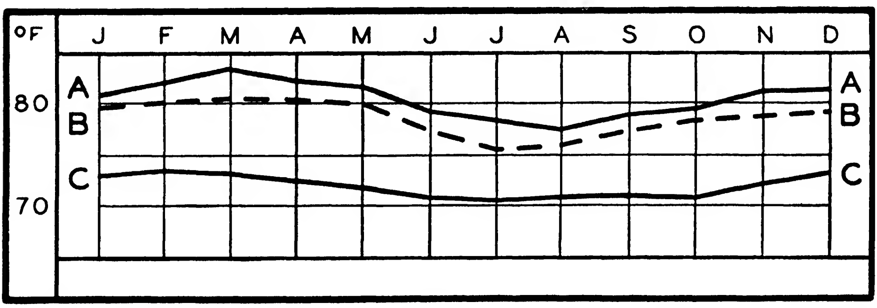

Fig. 92—Average Temperature. Tropical rainy (equatorial) climate of the Congo Basin and the Guinea Coast.

A. Lagos, Nigeria. B. Libreville, French Equatorial Africa.
C. Yaoundé, French Equatorial Africa.

small annual range, mostly less than 6°. Along the coast the monthly means range from about 77° to 83°, and the annual mean is above 80°. In the interior at elevations of 1,000 to 2,000 feet the annual means are between 75° and 80°, and the coolest month has a mean of 70° to 75°. Thus there is no interruption of the continuous heat. The daily ranges exceed the annual ranges, and they vary in different locations from 9° to 16°, the larger values occurring in the drier, clearer months. Maximum temperatures seldom or never exceed 100°, and minima are never below 60° in the lowland regions. The relative humidity is high at all seasons, and the sensible temperature is therefore high, too.

TRc *Climate of Africa*	*Annual Temp.*	*Annual Range*	*Daily Range*	*Av. Extremes*		*Rel. Hum., %*		*No. of Days*		*Annual Precip.*
				Max.	*Min.*	*Jan.*	*July*	*Rain*	*Thunder*	
Freetown	80.3	4.8	14	97	67	73	84	157	50	157.2
Lagos	80.5	5.6	11	95	67	74	82	123	52	71.6
Libreville	78.6	5.0	15	92	65	85	83	149	.	98 2
Douala	77.4	5.4	11	91	68	85	92	213	115	. . .

Guinea coast

Parts of the coastal plain are among the wettest lowland regions of the world, having an annual rainfall in excess of 120 inches. One of these areas embraces the larger part of Sierra Leone and Liberia. As the sun moves northward in the northern spring, and as low pressure develops in the interior over the Sudan and the southern Sahara, warm, moist air moves continuously inland and upslope along this coast as a moderate but constant southwest wind. In consequence the rainfall increases rapidly from April to May and again from May to June. Then, as the summer pressure conditions become well established, there is again a sharp rise to a remarkable maximum in July and August. By September, as the sun and the center of low pressure retreat southward, and as high pressure begins developing over the Sahara, the winds become light, shifting at times to northeasterly, and the rainfall decreases rapidly. The precipitous decline continues until December. In December the dry northeast trades from across the

desert become established, and there follows an almost rainless period of about three months, culminating in February. At Freetown (Fig. 93) the exceptional total of sixty-two inches falls during the

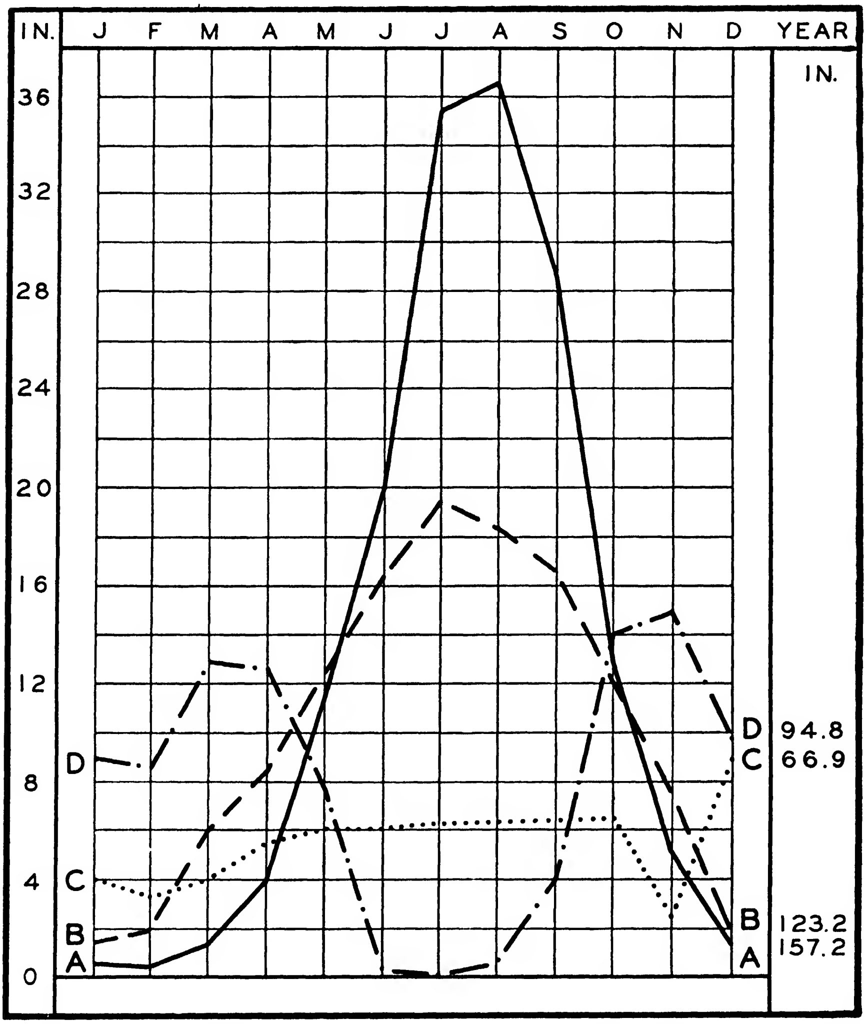

FIG. 93—Average Precipitation. Tropical rainy (equatorial) climate of the Congo Basin and the Guinea Coast.

A. Freetown, Sierra Leone. C. New Antwerp, Belgian Congo.
B. Calabar, Nigeria. D. Libreville, French Equatorial Africa.

two months of July and August, and the four months of June to September have a total of 110 inches. After the sharp rise in ele-

vation from the coastal plain, there is little further increase in elevation, and the rainfall decreases inland.

Another region of similarly heavy rainfall is the eastern part of the coast of Nigeria and the adjacent coast of Cameroon (Kamerun). (See Calabar, Fig. 93.) Here, the July-August peak is not quite so prominent, but a total of seventy inches, which is more than half the annual amount, falls during the four months of June to September. During the remainder of the year the rainfall is somewhat greater than at Freetown, for in this region southwest winds prevail throughout the year, although from December to February they are weak and subject to interruption by northeast winds. At Libreville, practically on the equator, there is a double maximum of rainfall, one in March-April, the other in October-November. These are the times of the migration of the pressure belts, following the two occurrences of the overhead sun. The dry period, amounting to an almost rainless period, is June, July, and August. This is the winter of the Southern Hemisphere, when the southeast trade winds extend northward to the equator.

The number of rainy days is 100 to more than 200, and the number of thunderstorms is forty to more than 100. Much of the rain along the coast is steady, orographic rain without the accompaniment of electrical storms. There are, however, occasional severe thunderstorms with high winds, causing damage to trees and buildings, and locally known as *tornadoes*. They are the result of frontal action where the dry continental northeast trades meet or overrun the moist, maritime air masses from the southwest. Hence, they are most frequent when these two air masses are most in conflict—that is, at the beginning of the rainy season and again as the rains cease. Along the coast from Nigeria to Sierra Leone, where these storms are most frequent, the period of greatest frequency is March to May, and a second maximum occurs in October and November. The storms move from the east or northeast as the front of the continental air mass moves westward.

Congo Basin

The rainfall in the interior of the Congo Basin is less than along the coast and is more evenly distributed throughout the year. There are, however, large differences in amount and in annual distribution, depending upon orientation with respect to the prevail-

ing winds. This in turn depends not only on direction of slope, but also upon position relative to the annual shifting of the pressure belts. One rainfall regime on the middle Congo, a few degrees north of the equator, is shown by the curve for New Antwerp (Fig. 93), where the total for the year is sixty-seven inches. The greater part of the Congo Basin has an annual rainfall of sixty to eighty inches. As compared with the similar rain forest climatic region of South America, the rainfall is greater along the African coast, but less in the interior Congo area than in the upper portion of the Amazon Valley. Orographic influences account for the differences, at least in part. In South America there is a gradual increase in elevation from the mouth of the Amazon to the slopes of the Andes. In Africa there is a sharp rise along the coast to heights of 1,000 to 1,500 feet, then a relatively flat basin surrounded by the higher continental plateau.

A wind that is characteristic of the northern portion of the tropical rainy province and of the savanna region farther north is the *harmattan,* a desiccating northeast wind often loaded with fine dust. This is simply the trade wind moving from the desert region with more than usual energy. It is comparable in character to the dust-laden "hot winds" of the southern Great Plains of the United States. By displacing the very humid air with air of extremely low humidity, however, the harmattan feels cool and affords some relief from the sticky heat, although the temperature remains high and the dust is unpleasant. Under the influence of the harmattan, however, the soil quickly bakes and vegetation wilts.

On the whole, the climate of the coastal region from the equator to 10° N. is at least among the worst in the world, and Sierra Leone has often been called "the white man's grave." Mental and physical energy are sapped, and there is constant fatigue and weakness. The coastal plains, however, are only twenty-five to fifty miles wide. The greater part of the area is the plateau above 1,000 feet, and its climate, though hot and monotonous, is not debilitating or unhealthful. Both temperature and humidity are lower than on the coast, and daily changes are greater.

Vegetation

The moist heat that is unfavorable to man is, together with the heavy rainfall, productive of a dense and luxuriant vegetation. A

large part of this entire climatic province is covered with a tropical rain-forest consisting of giant trees of many varieties. These are often so closely grouped that their foliage shuts out the sun's rays and prevents the growth of underbrush. Where they are not so crowded there is a dense undergrowth of tangled vines and bushes. The greatest of these forests are in the Congo Basin and in southern Nigeria, back of the coastal plain. On the inland borders of the province, on the north, east, and south, there is a gradual thinning of the forest as the dry season becomes longer and as savanna conditions are approached.

In the coastal plains and the river deltas there is much swampy land in which mangrove thickets are the characteristic vegetation. There is little agricultural land and little agriculture, but some cotton, indigo, tobacco, bananas, and various tropical fruits are produced—chiefly in the river valleys. Coffee and cotton are indigenous to the Congo Basin. The principal exports are rubber and valuable woods such as ebony and mahogany.

The African Savannas (TS)

The tropical rainy climatic province just described is bordered both north and south by a band about 5° of latitude in width in which the savanna type of climate (TS) prevails. A large area along the east coast of Africa has the same type of climate. Mean temperatures in these tropical savannas are not much different from those in the tropical rainy region, but the relative humidity is less and the rainfall is lighter, mostly twenty-five to fifty inches a year. There is a long dry, often almost rainless, season of three to six months, and hence forests give place to grasslands.

The northern savanna belt

In the Northern Hemisphere the savanna belt extends from the Atlantic coast of Gambia, Portuguese Guinea, and French Guinea eastward to the headwaters of the White Nile and the western border of Ethiopia. It includes southern portions of the great region known as the *Sudan.* In the lake region of interior Africa it stretches southward across the equator into the basin of Lake Victoria in northwestern Tanganyika, and a narrow strip crosses Lake Rudolph to connect with the savanna province of the east coast.

The rainfall of this region is directly responsive to shifting pressure belts. When the equatorial low is farthest north the savanna

is crossed by the rain-bearing southwesterly winds, and has four or five months (May to September) of moderate to heavy rainfall; the maximum is usually in August. As the center of low pressure moves south of the equator, the trade winds also migrate southward, resulting in dry northeast winds in the savanna province and in an almost rainless season of four or five months, November to March. The dry harmattan winds from the Sahara are of frequent occurrence at the end of the wet season, and the so-called *tornadoes* (*thunder squalls*) are most frequent toward the end of the dry season, February and March. Northern Nigeria is especially subject to these storms.

A peculiarity of this northern savanna belt is that it extends southward to the Guinea coast in Dahomey and the Gold Coast

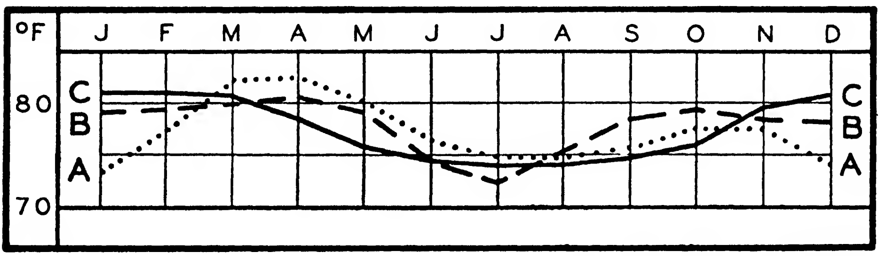

FIG. 94—Average Temperature. Tropical savanna climate of Africa.
A. Kaduna, Nigeria. B. Brazzaville, French Equatorial Africa.
C. Dar-es-salaam, Tanganyika.

Colony. (See data for Accra.) Westerly winds prevail all year along this coast, but in the northern winter they are almost parallel with the coast instead of onshore, and they are, moreover, cooled offshore by upwelling cold water. It is therefore dry here most of the year. There is a short rainy season in April, May, and June as the equatorial low migrates northward. The rainfall in the basins of Lakes Albert and Victoria is somewhat heavier than in other parts of this savanna province. There is some rain in all months, and thunderstorms are numerous. (See Entebbe.) The annual amount is moderate, however, in spite of the nearness of these basins to the equator. The region lacks the heavy rainfall typical of its latitude because it is bordered on east and west by high mountain ridges.

The southern savanna belt

On the southern border of the rainy province, the savanna belt

reaches from the equator to 10° South latitude along the Atlantic coast, including the delta of the Congo River and northern Angola. It narrows eastward, but includes most of the southern quarter of

Tropical Rainy and Tropical Savanna Climates of Africa	*Elevation (Feet)*	*Temperature, °F.*				*Precipitation (Inches)*		
		Mean Annual	*Coolest Month*	*Warmest Month*	*Annual Range*	*Annual*	*Wettest Month*	*Driest Month*
Guinea Coast (TR)								
Freetown	223	80.7	August 77.9	March 82.4	4.5	157.2	August 36.6	Feb. 0.3
Libreville	66	78.6	July 75.6	March 80.6	5.0	98.2	Nov. 13.9	July 0.1
Congo Basin (TR)								
Yaounde	2461	72 0	July 70.2	Feb. 73.9	3.7	62.2	April 9.1	Jan. 1.6
New Antwerp	1230	78.1	August 76.3	Feb. 80.1	3.8	66 9	Dec. 9.3	Nov. 2 6
Luluabourg	2034	76.5	Feb. 75.7	Dec. 77.2	1.5	60.8	Nov. 9.1	July 0.1
N. Savanna Belt (TS)								
Ouagadougou	2493	80.4	Jan. 74.7	April 88.5	13.8	32 0	August 10.6	Nov.–Feb. 0
Accra	60	78.7	August 74.7	March 81.3	6.6	27.2	June 7.0	Jan. 0 6
Mongalla	1140	79.0	August 75.7	March 32.6	6.9	38.9	August 5.8	Jan. 0.1
Entebbe	3863	70.0	August 68.6	March 71.3	2.7	58.0	April 9.7	Jan. 2.6
S. Savanna Belt (TS)								
Brazzaville	....	77.9	July 72.3	April 80.4	8.1	47.8	April 8.5	July 0
E. African Savanna (TS)								
Mombasa	50	78.5	July 75.3	March 81.8	6.5	46.0	May 12.6	Feb. 0.7
Zanzibar	...	80.2	July 76.7	Feb. 83.4	6.7	60.2	April 14.1	August 1.6
Mozambique	13	79.2	July 73.8	Dec. 83.3	9.5	39.3	Feb. 8.7	Oct. 0.1
Inhambane	46	74.5	July 68.5	Feb. 79.3	10.8	38.4	March 7.4	August 0.9

the Belgian Congo. The climatic conditions here are similar to those in the corresponding belt north of the equator, except that

the seasons are reversed. The wet season begins in September or October and continues until April or May. There is a rainfall maximum in November which is due to the southward migration of the equatorial low, and there is another and principal maximum in March or April because of the northward movement of the doldrums (See Brazzaville). Because of rising pressure and drier and

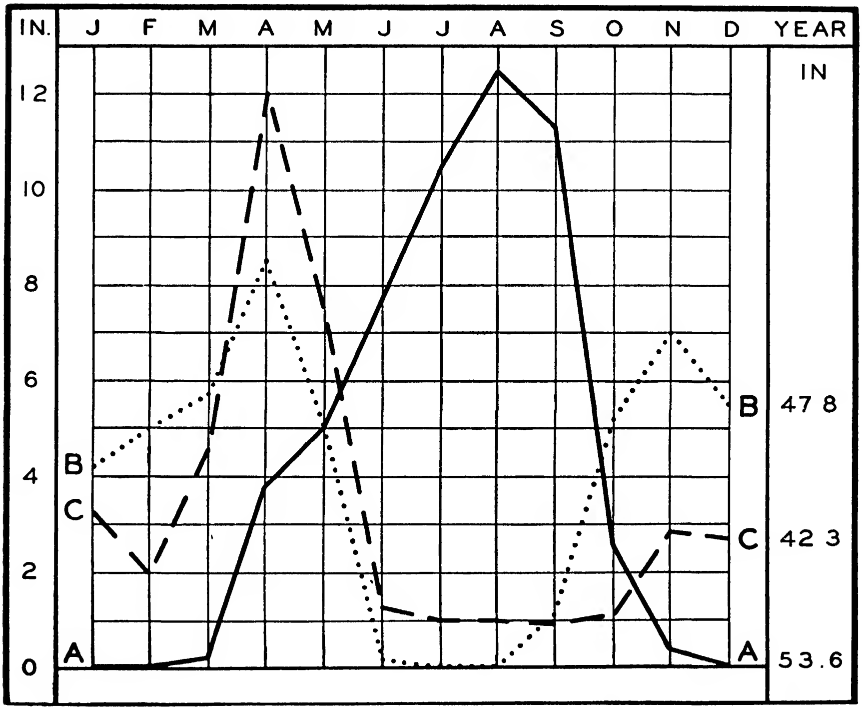

Fig. 95—Average Precipitation. Tropical savanna climate of Africa.
A. Kaduna. B. Brazzaville. C. Dar-es-salaam.

slightly cooler trade winds, June, July, and August are almost rainless.

East African savanna

Another large part of Africa with the same savanna type of climate is in the eastern coastal region. North of the equator it includes northern Kenya, southwestern Italian Somaliland, and southeastern Ethiopia, but it does not include the coastal plain of Italian Somaliland. South of the equator it extends along the coast to 25° South latitude, and reaches inland to the escarpment that marks the eastern boundary of the continental plateau. This

rather broad coastal strip is less than 1,500 feet in elevation, and includes practically all of Portuguese East Africa (Mozambique) and the Swahili Coast (the coast of Kenya Colony and Tanganyika Territory).

In the southern half of this east African savanna the southeast trade winds prevail throughout the year. Since the trade winds are dry except when the air is forced upward, the rainfall is light to moderate in the coastal region for a considerable distance inland, and then increases as the higher plateau areas are approached. In the southern winter this region is near the subtropical belt of high pressure in which the air is slowly descending. Hence the coastal plain receives little rain from May to October. In the southern summer the doldrum belt of ascending air is south of the equator, and the southeast trades are drawn inland toward the central area of low pressure. Consequently, the rainy season is the high-sun season, December–April.

In the northern half of this savanna province there are seasonal changes of wind direction. The southeast trades are well-developed from June to October, becoming a part of the southwest monsoonal circulation of the Northern Hemisphere. From December to March, the northern monsoon is established in the northern Indian Ocean and northeasterly winds extend southward along the East African coast as far as the town of Mozambique, for the equatorial belt of low pressure is then considerably south of the equator. The Swahili coast and the northern half of Mozambique receive their heaviest rains during this season, or during the transition season of April and May as the overhead sun moves northward. (Dar-es-salaam, Fig. 95.) Thus, although meteorological conditions are somewhat different in northern and southern portions, the entire region has a moderately wet season of five to six months, December to April or May, and a long dry season from May or June to November.

In the northern half of this coastal region, from Mozambique northward, the warm water from the equatorial drift of the Indian Ocean washes against the coast and contributes to its hot, moist, and oppressive climate. The result is a climate which is rather more objectionable than that in the corresponding savanna regions on the west coast, and which approaches the conditions found in the western tropical rainy regions. There is no latitudinal change in temperature from Mombasa to Mozambique, although the lat-

ter is 10° farther from the equator. In the southern half the effect of increasing latitude is felt, as is also the fact that the coast is less directly in the path of the drift of warm water. Accordingly, the temperature and humidity conditions are somewhat better. Annual ranges of temperature are less than 10°, except in the extreme south. Tropical cyclones from the southern Indian Ocean occasionally reach the Mozambique coast.

Physical features and vegetation

Throughout the savanna region of Africa there is much similarity not only of climate, but of physical features and native plant life, too. On both west and east coasts there are narrow coastal plains with swamps and lagoons lined with mangrove thickets. In these regions the climate is oppressively humid. From these plains the land rises rather rapidly by terraces to tablelands of moderate elevations of 1,000 to 5,000 feet. On these plateaus there are greater diurnal and annual ranges of temperature and decreased humidity. Although the mean annual temperature is almost as high as in the coastal plains, the climate of the plateaus is considerably less objectionable.

In the wetter locations there are some luxuriant forests of hardwoods, but most of the region is a grassland dotted with thin forests and bush, in which acacia and mimosa replace the hardwoods. Oil and date palms grow wild in abundance. Rubber vines, cotton, and coffee are indigenous also, and tobacco, bananas, oranges, and pineapples are grown in various places. Palm oil and rubber are important exports. The entire region is very slightly developed, partly because of the hot climate. The chief inhabitants are the native negro tribes.

The Tropical Highlands of Africa (TH)

In the absence of high mountain systems and extensive lowlands the greater part of Africa is a tableland of moderate elevation, but a large area of high plateau occupies much of east Africa from the southern end of the Red Sea almost to the southern extremity of the continent. Its elevation is generally above 3,000 feet, and a large part of it is above 5,000 feet. It averages 500 to 700 miles in width. The southern portion has a steppe climate which is described later. That part of it under consideration here

as a tropical highland climate (TH) reaches from latitude 15° N. in Ethiopia to latitude 20° S. in Southern Rhodesia, except for a narrow interruption in the Lake Rudolph region. These plateaus, lying wholly within the tropics, have a definitely highland or mountain climate. That is to say, elevation is a major factor in determining the climatic conditions. Because of its latitude, this region has a climate with the tropical characteristics of small annual range of temperature and absence of cyclonic storms. Because of its elevation it has lower temperatures and greater diurnal ranges of temperature than are ordinarily associated with tropical

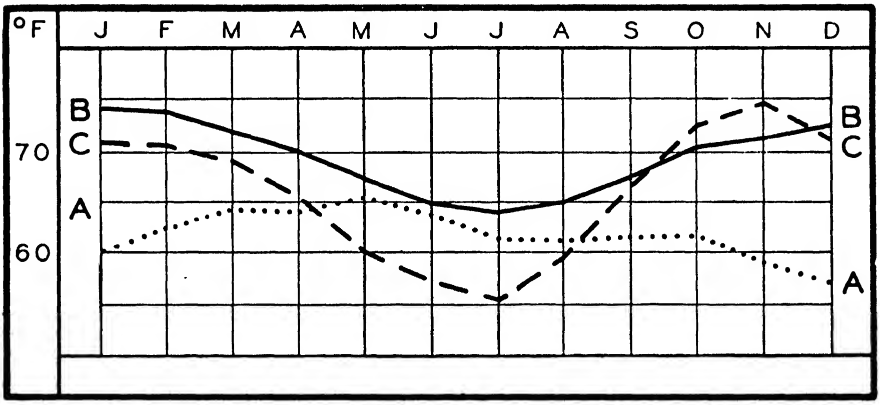

Fig. 96—Average Temperature. Tropical highlands of Africa.
A. Addis Ababa, Ethiopia. B. Moschi, Tanganyika.
C. Gwelo, Southern Rhodesia.

climates. The mean temperatures of the cooler months, and sometimes of all months, are below 65°, and frosts are not uncommon. Temperature conditions are thus more like those of subtropical lowlands than those of tropical lowlands.

Ethiopia (Abyssinia)

The highest portion of the African plateau is in the political subdivision known as Abyssinia or Ethiopia, and occupies all of that country except the northeastern and southeastern borders. This is the main portion of the high plateau that is north of the equator. The elevation of the greater part of it is between 6,000 and 12,000 feet. Ethiopia is within the influence of the great Asiatic monsoon system. In the winter of the Northern Hemisphere there are steady northeast winds, blowing out of the Asiatic center of high pressure toward the doldrum belt, which is then south of

the equator. As has been previously explained, this northeast monsoon is dry in Asia, and it remains dry as it reaches Ethiopia after crossing Arabia or a short expanse of the Arabian Sea. It gives some rain as it rises over the northeastern slopes of the highlands, but in general the Abyssinian winters (October–February) are very dry. (See Addis Ababa and Harar.)

In the northern summer the southwest monsoon is well-developed across Ethiopia, and it carries air from warm and moist equatorial latitudes to higher latitudes and greater elevations. This is therefore the rainy season in Ethiopia. The rains begin in March with the period of variable winds between the monsoons, become heavy in June as the southwest monsoon becomes well-established, and reach a well-marked maximum in August.

Tropical-Highland Climate of Africa (TH)	*Elevation (Feet)*	*Temperature, °F.*				*Precipitation (Inches)*		
		Mean Annual	*Coolest Month*	*Warmest Month*	*Annual Range*	*Annual*	*Wettest Month*	*Driest Month*
Ethiopia Addis Ababa	8005	62.1	Dec. 58.6	May 65.7	7.1	49.6	August 12.1	Dec. 0.2
Harar	6089	67.5	August 65.3	April 69.4	4.1	35.3	August 6.3	Dec. 0.4
Kenya Colony Nairobi	5450	63.2	July 58.5	March 65.2	6.7	39.9	April 8.9	July 0.9
Kisumu	3800	73.9	August 71.7	Jan. 76.9	5.2	45.8	April 7.0	July 2.0
Tanganyika Tabora	3983	72.6	March 70.5	Oct. 77.7	7.2	33.5	March 6.7	July Aug. 0
Belgian Congo Elizabethville	4500	68.9	July 60.3	Oct. 74.8	14.5	47.1	Dec. 11.4	June–Aug 0
Nyasaland Zomba	3130	69.4	July 62.1	Nov. 75.6	13.5	55.3	Jan. 11.1	July 0.3
Northern Rhodesia Livingstone	3000	73.1	June 63.9	Oct. 80.8	16.9	29.9	Jan. 7.6	June–Aug. 0
Southern Rhodesia Salisbury	4880	65.3	July 56.1	Nov. 70.7	14.6	31.9	Jan. 7.5	July 0

Rainfall remains rather heavy in September, but it declines rapidly in October and continues light until March. Because the rain-bearing winds are from the southwest, the rainfall tends to be

heaviest in the west and southwest, decreasing eastward and northward; the annual amount is subject to much local variation, however, because of differences of slope and elevation. Most of the plateau receives forty inches of rain a year, and some areas receive as much as seventy-five inches, but the amount decreases to about twenty inches at places in the north. The rainfall is orographic and convectional in character, and there are heavy downpours and many thunderstorms. The Abyssinian summer rains are the main source of the Nile floods which irrigate the lower Nile Valley.

Temperatures show a direct response both to elevation and to wind movement and cloudiness. The average annual temperature decreases two or three degrees for each 100 feet of increase in altitude. The warmest months are March, April, and May, the season of light variable winds and high sun, before the heavy rains begin. The temperatures decline during June, July, and August because of much cloudiness and heavy rains. They rise to a secondary maximum in September and October with the coming of the autumn season of changing monsoon winds, and then fall to a minimum in December and January, when the sun is lowest.

Some of the valley bottoms are below 6,000 feet, and in these the air is quiet and sultry, and the climate is truly tropical in character. The most favorable climate is that at elevations of 6,000-8,000 feet. Here the mean annual temperature is 62° to 68°, about equal to that of Los Angeles, California, Montgomery, Alabama, and Athens, Greece, but the seasonal changes are smaller than at these cities—much smaller than those at Montgomery. The warmest months have a mean of 65°–70°, and the coolest months 58°–65°; the annual range is about 4°–8°. It is a pleasant and healthy climate, but rather too uniform to be invigorating. Night frosts are not uncommon, but the general air temperature remains above freezing and the fertile plateaus at these elevations are well adapted to the production of such subtropical fruits as figs, oranges, and pomegranates, as well as of cotton, coffee, indigo, and sugar cane. Ethiopia is the home of the most important species of coffee. Above 8,000 feet the months are all cool, and freezing temperatures are frequent. At this elevation the climate is adapted to the production of a great variety of hardy grains and vegetables not requiring high temperatures. Cereals are grown to an elevation of 12,000 feet. In its native condition the Abyssinian

highland is a grassland with scattered trees and bushes and with occasional thickly wooded areas in ravines and depressions.

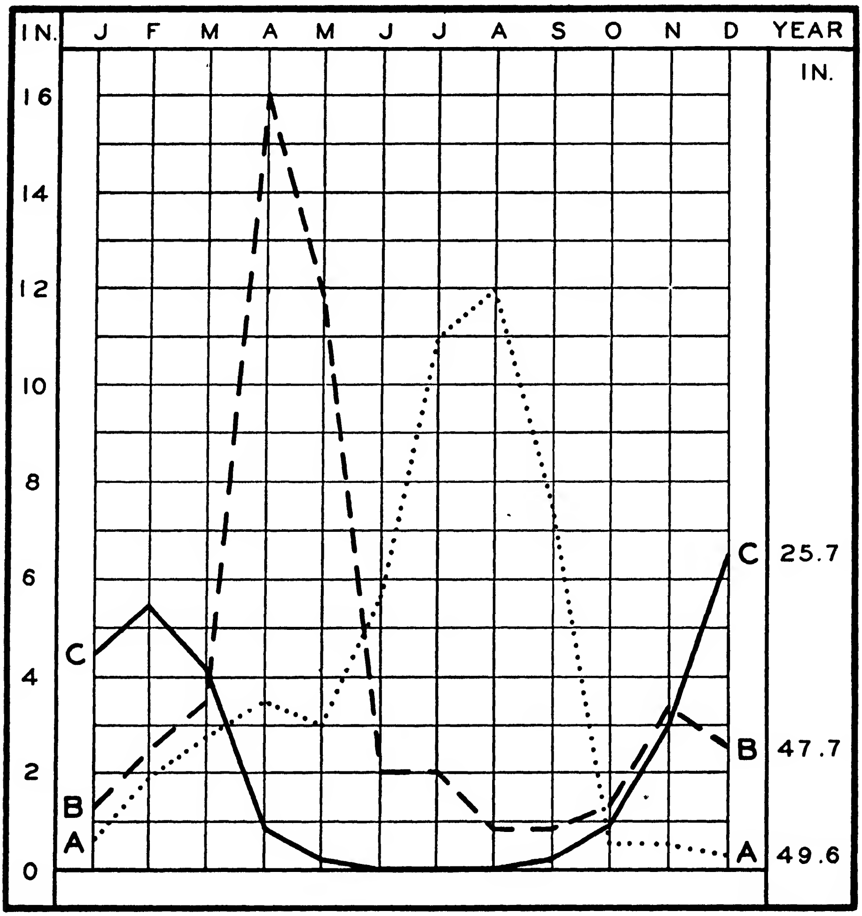

FIG. 97—Average Precipitation. Tropical highlands of Africa.
A. Addis Ababa. B. Moschi. C. Gwelo.

The southern African highlands

In the southern hemisphere there is an extensive high plateau similar to that of Abyssinia which reaches from the equator in Tanganyika Territory to latitude 20° S. in Southern Rhodesia, and westward from Northern Rhodesia into central Angola. The climate is similar to that of Abyssinia and is similarly controlled by the shifting pressure belts, but the seasons are reversed.

In the summer of the Southern Hemisphere, November–March,

there is a center of low pressure over the interior of this plateau and adjoining portions of the Belgian Congo, with light and variable but generally inflowing and rising air currents. This is a part of the doldrum belt, which here, as elsewhere, is characterized by much convectional precipitation. In the winter half-year, April–September, the subtropical high pressure belt has a center over South Africa, and the tropical highland area is north of the center of high pressure. Hence, the winds over the plateau are mostly southerly, and in consequence become warmer and drier as they move equatorward. For these reasons, summer is the rainy season throughout the southern tropical highlands, and winter is almost rainless.

The seasons are of equal length, and their beginnings and endings are strongly marked. The rains begin in September and continue until March or April. There is then a sudden drop to arid conditions which continue for six months and then end abruptly. 90% to 95% of the annual rainfall occurs in the six months of the summer half-year. There are large local variations in the annual amount, but in general the total decreases from north to south and inland from east to west. In Tanganyika the annual totals range from forty to sixty inches. In Nyasaland and Northern Rhodesia the amounts are mostly between thirty-five and forty-five inches, but as much as eighty inches falls in some places. In Southern Rhodesia the annual rainfall is twenty to thirty inches.

The general elevation of the southern plateau is from 3,000–6,000 feet, with a large portion between 3,000 and 4,000 feet. It averages lower than Abyssinia, and, accordingly, the temperatures average higher except in Southern Rhodesia, where the greater distance from the equator becomes effective in lowering the temperature. The warmest months are the spring transition months of October and November, just before the heaviest summer rains begin. The heavy rains result in a drop of several degrees in the mean monthly temperatures. Near the equator, in Tanganyika Territory, the months of heavy rain are the cool months, in spite of the fact that they are high-sun months. South of latitude 10° S. the lowest temperatures occur in the midwinter season, June, July, and August.

The greater part of Tanganyika is uncomfortably hot and humid, approaching the climate of the tropical lowlands, but areas

over 6,000 feet in elevation are favorable, just as are those of similar elevations in Abyssinia. In Rhodesia, Nyasaland, and central Angola, all lying between 10° and 20° from the equator, favorable climates exist at a lower elevation. Here, at heights above 3,000 feet, moderate temperatures prevail throughout the year. During the cooler months, May–August, maximum temperatures are seldom above 75° or 80°. At night temperatures fall to between 40° and 60°, and light frosts occur occasionally at ground levels, although the temperature of the air a few feet above the ground remains well above freezing. The relative humidity is moderate, averaging about 60%. During the short hot season in October and November maximum temperatures reach 95°—rarely 100°—and minima are approximately 65°. The height of the rainy season is the most disagreeable part of the year, for, though the highest temperatures are mostly between 80° and 90°, the humidities are rather high and the nights are warm. At this season the lowest temperatures are often between 70° and 80°. On the whole, the climate of these tropical highlands is one of the excellent climates of the world, without extremes, and also sufficiently variable to be without monotony.

Vegetation

The tropical highlands of Africa are primarily grasslands. The long season without important amounts of rainfall prevents the growth of forests. On slopes favorably situated to receive some winter precipitation there are park-like areas dotted with mimosa and other shrubs, and some mountain areas are densely forested. The greater part of the land is unused and remains covered with its native grasses, but it is well adapted to the production of coffee, and there are some large coffee plantations, especially in Abyssinia and Tanganyika. A great variety of grains, vegetables, and subtropical fruits is grown for local use.

Madagascar

The large island of Madagascar, which lies off the coast of Mozambique between latitudes 12° and 25° S., has all three types of Humid Tropical Climate. The general trend of the island is from south-southwest to north-northeast. On the eastern side it has a narrow coastal plain which is ten to fifty miles in width.

From this plain the ground rises by successive ranges of hills to a high interior plateau of 4,000–6,000 feet elevation, and then descends to a broader plain about 100 miles wide on its western side. It lies wholly within the southeast trade wind belt, except in the high sun period, December–February. In those months the doldrums overlie northern Madagascar, and the northeast monsoons therefore cross the equator; they are then deflected to the left and become northwest winds in the northwest portion of the island.

East coast. The eastern side of Madagascar has a tropical rainy climate of the trade wind subtype (TRt). It is the windward side throughout the year, and as the air moves up slope rain falls in all months. The rain is heaviest in summer, when the low pressure belt overlies the island and when convection is active. For several months the average rainfall is more than twelve inches a month, and the annual total is over 100 inches. Much of the rain is of the slow, long-continued, orographic type, but tropical cyclones from the Indian Ocean, attended by high winds and heavy downpours of rain, occasionally move westward across Madagascar. These are most frequent in January, February, and March. In spite of the heavy rain there is much bright sunshine. The average cloudiness is about 0.5, and the number of rainy days is about 190 a year.

Temperatures are tropical all year. The coolest month, July, has a mean of about 69°, and the warmest month, February, has a mean of about 80°, thus giving an annual range of 11°. The daily range averages 15°. Extremes of temperature are moderate; temperatures seldom reach 100°, and frosts are unknown. Tamatave has the same mean annual temperature as Honolulu, but it has an annual range 3° greater. The flora of eastern Madagascar is of the tropical rainforest type. The forests contain several species of hardwoods that are not found elsewhere. There are also palms and bamboos.

Western plains. The western plains of Madagascar in the lee of the plateau have a tropical savanna climate (TS), hotter and drier than the east coast. As has been previously explained, the northwest portion has northwest monsoon winds in summer, and receives heavy rain in the summer months, the annual total amounting in places to 100 inches. The amount decreases rapidly southward, falling to sixty inches in the central portion of the west

coast and to only sixteen inches in the extreme southwest, which is under the influence of the subtropical high pressure belt. The major part of the rainfall of the western plains occurs in summer when the doldrums are farthest south. Along the entire length of the western lowlands the winters are dry under the influence of steady southeast trade winds descending from the plateau. Temperatures are similar to those of Mozambique. All months average above 70°, and maxima above 100° are not unusual. This region is mostly a grassy plain with scattered clumps of trees. There are some forests in the north. In the extreme south the vegetation is xerophytic, and a small area might be classified as *low latitude steppe*.

Highlands. A narrow plateau at an elevation of 4,000–6,000 feet extends the entire length of Madagascar, and has a tropical-highland climate (TH) similar to that of Rhodesia at like elevations, but with somewhat heavier rainfall. The heaviest rains are in the summer months, December–March, as elsewhere on the Island, and the winter half-year, April–September, is almost without rain, as in the western lowlands. The yearly total is sixty to seventy inches. Temperatures at altitudes of 4,000–5,000 feet are 10° lower than in the lowlands. Mean temperatures are below 65° for four or five months. The annual range is about 10° to 12°, as in the lowlands, but the diurnal range is about 20°. Maximum temperatures seldom exceed 90°; night temperatures are sometimes as low as 40°, and light frosts are not uncommon. Rice, corn, millet, and subtropical fruits are produced.

CHAPTER XXII

Subtropical Climates of Africa

The humid tropical climates described in the previous chapter cover almost one-half of the area of Africa. The remainder of the continent is subtropical in character, and much the greater part of it is arid or semiarid. A small part of the semiarid region is tropical in its temperature conditions, and another small and elevated area approaches the character of an intermediate climate, but in general the temperature conditions conform to the definition of subtropical climates.

The Steppes and Deserts of Northern Africa

In contrast to equatorial Africa and the Guinea coast, where the rainfall is heavy to excessive, approximately half of the continent has less than twenty inches of rain a year. Those dry areas, constituting the great low latitude steppes and deserts of Africa, are centered about the Tropics of Cancer and Capricorn. In the Northern Hemisphere there is the Sahara, the largest of all deserts, extending clear across the continent, and except for the intervention of the narrow Red Sea, continuous with the Arabian Desert. The Sahara is bordered both north and south by relatively narrow semiarid strips which form transition zones between the desert and more humid areas. In the Southern Hemisphere most of the interior south of latitude 15° S. is a steppe region, and a belt along the west coast is desert.

The Sahara

As a climatic province, the Sahara Desert extends from the Atlantic coast between latitudes 19° and 29° N. to the Red Sea between latitudes 15° and 30° N., broadening in the interior, so that its latitudinal extremes are about 14° and 33° N. It is bisected by the Tropic of Cancer and is accordingly in the center of the trade wind belt. In the winter the subtropical ridge of high pressure is

over the northern portion of the desert, and its center is in the northwest portion. The center of low pressure is in the interior south of the equator. Hence, along the northern border the winds are light and variable and sometimes from the west, marking the boundary between the westerlies and the trades, but in the central and southern portions of the desert the northeast trade winds blow with great regularity.

In the summer the ridge of high pressure lies across southern Europe, and the trough of the doldrums is over the Sudan. Consequently there are steady northeast trades, from high to low pressure, throughout the northern and central portions of the Sahara, but on the Sahara's southern border these are sometimes interrupted by southwesterly winds from the Gulf of Guinea. The southern boundary of the desert is marked by this transition zone between the dry northeast trades and the moist southwest monsoons. On the whole, northeast winds prevail all year throughout the Sahara—very regularly in the interior, but subject to some interruption on the northern and southern borders as the transition zones are approached.

As has been indicated in previous chapters, the regions of the subtropical high pressure belts and of the trade winds are normally dry regions because the subsidence of air in the highs and the equatorward movement in the trades both conduce to increasing temperature and decreasing relative humidity. Even where the trade winds move inland from great stretches of warm ocean, they produce little rain except where there is orographic uplift. The Sahara is the largest continuous expanse of land in the trade wind belt, and it has no extensive mountain systems to force the air to rise. Moreover it has a great continental mass, mostly dry, on its east and northeast. These are the reasons for the great aridity of the region. Air enters northern Africa warm and dry, and it becomes hotter and drier as it moves over barren land toward the equator.

The Sahara must not be thought of, however, as a uniform surface of barren, shifting sand. There are such areas in the Sahara—regions where " boundless and bare, the lone and level sands stretch far away "— and there are other regions where the undulating surface of the dunes appears limitless. Actually, however, only a portion of the Sahara is like that. There are hills and mountains

rising to heights of 5,000–6,000 feet above sea level, but there are also some valleys and depressions which are slightly below sea-level. There are large tracts of hilly, rocky surfaces, and there are vast areas of loose stones and water-worn pebbles. Nor is the desert entirely bare of vegetation; grasses and thorny bushes grow in many places, and in the oases there is luxuriant vegetation.

Egypt. The greatest of the oases is the Nile Valley, for Egypt is a true desert, no different from the rest of the Sahara except for the narrow valley and broad delta that are annually flooded by water and sediment which come mostly from the Abyssinian highlands. In Egypt's upper (i. e., southern) portion this fertile, intensively cultivated valley is only about two miles wide, and, in its lower portion, about ten miles. The delta at the mouth of the Nile is about 100 by 150 miles. In this small area are fifty centuries of human history. The date palm is the characteristic tree throughout Egypt and the other oases of the Sahara. Grapes, oranges, lemons, pomegranates, figs, and olives also abound. The climate of the lower valley and the delta is particularly adapted to cotton, and this region is one of the principal cotton-producing regions of the world. Sugar cane is grown in the upper Nile Valley.

Temperature. In the heart of the Sahara there is a large area in which the July temperatures average above 95°, the most extensive region in the world with such high average temperatures. At In Salah in central Algeria the July mean is 99°. (The July mean at Yuma, Arizona, is 91°; at Needles, California, 94°; and at Greenland Ranch, Death Valley, 101°.) In the central Sahara maxima above 120° are to be expected every year, and temperatures up to 130° are not uncommon. In Salah has a record of 133°, and the world's record of 136.4° was observed at Azizia, Libya.

In the dry air of the desert there is rapid heating by day and rapid cooling by night. Hence the daily range of temperature is large, averaging 35° in large areas, and often exceeding 45°. The day temperatures are so high, however, that the nights are uncomfortably hot in summer despite the large daily range; the average minima are between 70° and 80°. Similarly, there is a large annual range of temperature, and the winters are comfortably cool in the Sahara, especially in the northern half. Throughout the northern and central portions of the desert there are three or four

months which have mean temperatures below 65°; frosts occur in most places, and temperatures occasionally fall a few degrees below freezing. The region is thus subtropical rather than tropical. In Salah has an absolute minimum of 25°, and an absolute range of 108°. Its mean annual range is 44.6°—from a July mean of 99.3° to a January mean of 54.7°. This is an unusually large annual range for a low latitude station. Miami, Florida, in the same latitude, but with a marine climate, has an annual range of 15°.

That portion of the Sahara south of latitude 20° N. is more nearly tropical than are the northern and central portions. In this southern portion all months average above 65°, and frosts are rare but not entirely unknown. The warmest part of the desert in terms of annual averages is the southern part of the Red Sea coast. The Red Sea, a narrow, elongated body of water set in the midst of hot deserts, is warm at all seasons, and, because of prevailing winds and added humidity, it is particularly effective in maintaining high winter temperatures along its western shore. At Berbera, Somaliland, three consecutive summer months, June, July, and August, have mean temperatures above 95°, and the coolest months are January and February, which have means of 76°. The annual range here is only 21.3°, less than half of that at In Salah. The increased humidity and decreased range of temperature give the western shore of the Red Sea a climate suggesting that of the Guinea coast in spite of the great contrast in rainfall.

Throughout the Sahara, the intense heating by day results in unstable air and strong winds; the stability produced by radiation cooling at night results in quiet conditions. Windy days and calm nights are therefore characteristic of the Sahara. Even moderate winds pick up much dust. Dust storms are frequent and are one of the major discomforts of the climate. This is the home of the sirocco, the severe dust storm that sometimes crosses the Mediterranean Sea into Italy and Greece. The word *sirocco* implies *poisonous*. In Egypt severe dust storms brought by hot, dry southerly winds occur at times, and are called *khamsins*. Along the Mediterranean coast of Egypt the heat is tempered by the influence of the comparatively cool water, and the summers at Alexandria and Cairo are not extreme on the whole although there are occasional days with maximum temperatures above 100°.

Precipitation. The Libyan Desert and much of the middle Nile Valley are practically rainless. Much of the rest of the Sa-

hara receives less than one inch of rain a year, and almost all of it receives less than five inches. Along the northern and southern borders and possibly in some of the isolated mountain ranges, however, the average may reach ten inches. Average monthly or annual amounts mean little, however, because such rain as does fall occurs in heavy showers at long intervals. A place may be entirely without rain for five to ten years and then receive a heavy shower of one or two inches in a few hours.

In winter and spring when cyclonic storms move eastward across southern Europe and give rain along the European shores of the Mediterranean, secondary depressions sometimes form in Libya and move slowly across northern Egypt. On the eastern side of these depressions southerly winds continue for two or three days, bringing hot, dry, hazy tropical air northward to northern Egypt; these winds cause a sharp rise in temperature and a fall in relative humidity, frequently to 10% or less. These are the khamsin conditions, which sometimes become severe sandstorms reducing visibility to 100 yards. The cyclonic depressions have a well-developed cold front on their western sides, marking the advent of an air mass from the Mediterranean Sea or from southern Europe. With the change to northerly winds at the cold front there is a sharp drop of 20° to 30° in temperature, an increase in relative humidity, and frequent light showers. In this way northern Egypt gets some rain during the winter months. The annual amount, which is about eight inches at Alexandria, decreases rapidly inland, and is only 1.3 inches at Cairo.

The southern border of the desert is rainless during the winter months, under the influence of the steady northeast trades, but in late summer, when the interior center of low pressure is farthest north, moist southwesterly monsoon winds extend into the desert and give occasional showers. Khartoum thus receives 5.1 inches a year, mostly in July and August, and Timbuctu, on the edge of the steppe, has 9.1 inches, also heaviest in July and August. Rainfall in the northern Sahara thus follows the Mediterranean regime, and, in the southern Sahara, the tropical steppe and savanna regime.

Low latitude steppe regions of northern Africa

Along the entire southern border of the Sahara there is a rather narrow transition region which separates the desert from the tropi-

cal savannas on the south. This belt forms the northern portion of the Sudan. It has a long dry season and a short wet season. Under the influence of the northeast trades there is no rain of importance from October to May, but during June, July, August, and September the southwest monsoons prevail and bring moderate rainfall which is heaviest in July and August. At El Obeid in the Anglo-Egyptian Sudan the annual amount is fourteen inches; at Zinder in the Lake Chad region it is twenty-two inches. The rainfall is largely in the form of thunderstorms.

Temperatures are comparable to those in the southern portion of the desert except during the rainy season. May, which is almost clear, and which has an overhead sun moving northward, is the warmest month. With increasing cloudiness and increasing rainfall there is a decrease in mean temperatures from May to August and then an increase in September as the skies become clearer. The effect of the cloudiness is felt chiefly in lower afternoon maxima—that is, in the absence of extremely high temperatures during these months. In the southern and eastern parts of the steppe region there is some fertile arable land and much good grazing land, and there are forests along the river banks. To the north and west there are short-grass prairies and occasional patches of acacias.

North of the Sahara there is also a belt of land having a steppe climate. This stretches across Morocco and Algeria, separating the desert from the coastal strip that has a Mediterranean climate, and it reaches to the Mediterranean shore in Libya and central Tunisia. In the interior the summer temperatures are high, but somewhat less than in the heart of the desert. July and August have mean temperatures above 90° but below 95°. The winters are comfortably cool, and there are occasional frosts in the interior. In the Atlantic and the Mediterranean coastal areas the heat of summer is considerably tempered by marine influences, and the winter temperatures are kept somewhat higher than at inland stations. The summers are under the influence of dry northeast winds and are almost rainless. During the remainder of the year, October to April, westerly winds and travelling depressions account for light to moderate rainfall. Annual amounts vary from about six to sixteen inches. In the drier interior the vegetation is the typical steppe covering of coarse grasses and scattered shrubs. In the

coastal regions the date palm is characteristic, and other sub-tropical fruits are also grown.

The Steppe and Desert Regions of Southern Africa

In the trade wind belt of the Southern Hemisphere, corresponding in latitude to the Sahara and its adjacent steppes, there is a

Steppes and Deserts of Africa (STS *and* STD)	*Elevation* (*Feet*)	*Temperature, °F.*				*Precipitation (Inches)*		
		Mean Annual	*Coolest Month*	*Warmest Month*	*Annual Range*	*Annual*	*Wettest Month*	*Driest Month*
Sahara								
In Salah	919	77 7	Jan. 54 7	July 99 3	44.6	Almost no rain		
Alexandria	105	67 5	Jan. 56 1	Aug. 78.1	22 0	8.0	Dec. 2.6	5 months 0
Cairo	98	68 2	Jan. 52.7	July 81.0	28 3	1.3	Jan. 0.4	5 months 0
Wadi Halfa	421	75 7	Jan. 57 9	July 88.5	30.6	Almost no rain		
Khartoum	1280	82.8	Jan. 70.3	June 91 4	21 1	5.1	Aug. 2.2	6 months 0
Berbera	31	85.0	Jan. 76.1	July 97.4	21.3	2.4	March 0.7	3 months 0
Desert of S.W. Africa								
Walvis Bay		62 0	Aug. 56.8	March 66.4	9 6	0 5	April 0.2	8 months 0
Port Nolloth	16	57 6	Aug. 53 8	Dec. 60.3	6.5	2.3	May 0.4	Jan.–Oct. 0
O'okiep	3035	63 2	June 53.0	Feb. 73 3	20.3	6 7	June 1 13	Dec. 0.2
Steppes of N. Africa								
Timbuctu	820	84 4	Jan. 71.1	May 94.5	23.4	9.1	July 3.5	5 months 0
El Obeid	1866	77.7	Jan. 67.3	May 85.8	18 5	14.0	Aug. 4.5	5 months 0
Biskra	410	71.2	Jan. 52.7	July 92.3	39.6	6.9	April 1.2	Aug. 0.1
Tripoli	56	66.2	Jan. 54.0	Aug. 80.2	26.2	16.3	Dec. 4.7	July–Aug. 0
Steppes of S. Africa								
Windhoek	5456	66.2	July 55.6	Jan. 74.3	18.7	14.8	Jan. 3.9	June, Sept. 0
Kimberly	4042	64 4	June 50.3	Jan. 76.2	25.9	16.2	March 2.9	Aug. 0 2

large dry area bisected by the Tropic of Capricorn. In several particulars this southern dry province is quite different from the Sahara and the Sudan. Topographical, geographical, and oceanographical factors account for the differences. In the first place the continent is comparatively narrow in these latitudes and is bordered by wide stretches of ocean. The trade winds arrive from extensive ocean areas rather than from extensive land areas. In the second place, all the interior of southern Africa is a plateau with a general elevation of 4,000 to 6,000 feet. Its climate is modified by its elevation, but it is separated from the tropical highlands of east Africa because it is semiarid rather than humid. It also has somewhat lower temperatures.

A third reason for the special characteristics of the south African climate is the distribution of ocean temperatures along its coasts. On the eastern coast the warm Mozambique Current contributes to a good moisture supply and to higher winter temperatures than would otherwise occur. The cold water of the Benguela Current along the west coast depresses both the temperature and the rainfall. The prevailing winds of the region are the trade winds from the Indian Ocean, but the ridge of the subtropical belt of high pressure overlies the southern portion, and in it the winds are often light and variable. This is especially true in winter, when the pressure belt moves northward and causes a center of high pressure to develop over the plateau. At all seasons there are some southwest or west winds which blow inland toward the equatorial area of low pressure.

The semiarid plateau

There are narrow coastal strips on the east, south, and west from which the plateau rises rather abruptly to occupy the entire interior. This plateau has a warm steppe climate (STS). The trade winds arrive at the eastern and southern coast lines warm and moisture-laden, giving these coastal strips a humid climate, and losing much of their moisture by the time they reach the plateau. As they move across the plateau, which has a gentle downward slope from east to west, they give little rain, especially in the western portion. Most of the rain falls in the summer half-year, October to March, when pressure is lower in the interior and when

convective instability is greatest. Under anticyclonic influence the winters are quiet, clear, and almost rainless. Annual amounts of precipitation vary considerably according to local topography, but in general they range from about twenty-five inches in the east to ten or fifteen inches in the west. There is also much variability in the totals from year to year. Much of the rain falls in local thunderstorms, which are sometimes violent and attended by destructive hail storms.

Temperatures are moderate and much the same throughout the plateau. The mean annual temperature ranges from about 61° to 66°. The warmest month, usually January, has a mean of 70° to 76°, and the coldest month, July, a mean of 50° to 57°. Four to six months average below 65°. The temperature conditions are warm subtropical. In most of the region maximum temperatures do not exceed 100°, but summer maxima above 90° are usual. Frosts occur throughout the plateau, and temperatures below 25° are recorded occasionally. Light frosts are often the result of rapid radiation cooling in the clear thin air of the plateau, but the lowest temperatures are usually caused by the import of cold air from the south in the rear of a traveling cyclone.

The region is largely a grassland locally known as *veld.* In the southeast there are large areas of rolling, treeless, grass-covered uplands with much excellent tall-grass pasturage. Other areas, especially in the north and west, are known as *bush veld,* and have tall coarse grasses interspersed with acacia trees, shrubs, and bare spaces. The western region, often called the *Kalahari Desert,* is mostly of this bush veld type and is here classed as *steppe,* but it merges into a true desert condition as it approaches the western coastal desert. Stock raising is the principal agricultural pursuit throughout this semiarid plateau. The southeast portion has the greater part of the population and has some cultivated land producing wheat, corn, and "Kaffir corn."

The coastal desert

Along the coast of southwest Africa desert conditions prevail for a thousand miles, from Mossamedes in southwestern Angola to the Olifants River in the Cape Province. For most of its length this strip is fifty to 100 miles wide, but at its southern end desert

conditions extend 200 miles inland and include much of the lower Orange River Basin. The entire region is extremely arid. On the immediate coast the annual rainfall is less than two inches; Walvis Bay has only half an inch a year. Farther inland, as the mountains are approached, the amount rises to four or five inches. An important climatic control of the region is the cold Benguela Current which flows northward off the coast. The contrast between the temperature of this water and of the tropical interior of the continent results in inflowing west or southwest winds throughout the year. Since this air is warmed as it moves inland, it yields little or no rain until it is forced a considerable distance upward on the western slopes of the mountains.

In the northern two-thirds of the desert such rain as occurs falls entirely in summer in the form of thunderstorms at rare intervals. In the southern third there is a little rain in all months; in the summer months there is an occasional thunderstorm, and in the winter months an occasional rain occurs in connection with a traveling cyclone originating in the prevailing westerlies farther south. The presence of the cool water offshore, although reducing the rainfall to almost nothing, results in much fogginess. The air from the warm water farther out to sea is reduced to its dew point in passing over the cold current, and the fog thus formed is carried to the coast by the westerly winds. These fogs are so dense and so frequent as to minimize evaporation from plants and soil and to add an appreciable amount of moisture, thus helping to support the xerophytic vegetation of the region. Because of the fogginess the average relative humidity is high, 84% at Walvis Bay. The country is decidedly arid, but the air is uncomfortably moist much of the time. This apparent contradiction illustrates the fact that moist air alone does not insure precipitation; some physical process producing rapid condensation and coalescence of droplets or snow particles is also necessary.

Although this region is extremely dry and partly within the tropics, it is not a hot desert. Here, again, the cool water and the westerly winds off the cool water exercise a marked influence. The temperature at the coast is remarkably low for the latitude, the annual mean averaging from 57° to 64°. The summers are especially cool along shore, the warmest month having a mean of about 65°; inland the January and February means rise above 70°. The mean

›f the coolest month is about 55° throughout the region. The an-ıual range is less than 10° at the coast, but rises to 20° in the nterior.

Note the contrast between the temperature of the east and west ›oasts of South Africa: Walvis Bay at the Tropic of Capricorn has ı mean annual temperature of 62.0°; Inhambane in the same lati-ude on the east coast has a mean of 74.5°. The difference in the nonthly means is about 14° in October, November, and December, ınd about 10° in May, June, and July. Walvis Bay, however, has ı counterpart in Antofagasta, Chile, where the mean annual tem-›erature is 63.0°, under the influence of a cold ocean current. In ;eneral the air in this South African coastal desert comes from the ›cean and is cool and humid, but occasionally during the winter nonths an east wind moves down the slopes, assumes foehn char-ıcteristics, dissolves the fog, and produces a hot and dry day. Here s another paradox of the region: the warmest days occur in win-.er. The principal wealth of the desert is in its mines—especially ts copper and diamond mines.

The Humid Subtropical Climate of Southeast Africa (STH)

Along the southeast coast of Africa there are narrow coastal plains from which a succession of terraces leads inland to the high-and steppes of the interior. From the southern extremity of Mozambique to Algoa Bay, latitude 31.5° S., the coastal region and the first plateau up to a height of about 2,000 feet have a humid

STH and STM *Climates of South Africa*	*Elevation (Feet)*	*Temperature, °F.*				*Precipitation (Inches)*		
		Mean Annual	*Coolest Month*	*Warmest Month*	*Annual Range*	*Annual*	*Wettest Month*	*Driest Month*
STH								
Durban	200	70 5	July 64.3	Feb. 76.8	12.5	42.7	March 5.4	July 1.2
Pietermaritzburg	2225	66.6	June 57 6	Feb. 73.4	15.8	35.9	Feb. 6.2	July 0.1
STM								
Port Elizabeth	181	63.6	July 57.9	Feb. 69.7	11.8	22.5	May 2 4	Jan. 1.2
Capetown	40	62 3	July 54.7	Feb. 70.3	15.6	25 3	June 4 5	Feb. 0 6

subtropical climate (STH) similar to that of extreme southern Brazil and that of the Gulf and south Atlantic coasts of the United States. This coastal region is washed by the warm Mozambique Current; the prevailing winds are onshore across this current; and there are no large continental masses in higher latitudes to serve as sources of cold air in winter. Hence the region has a warm marine climate of small variability.

The mean annual temperature is 60° to 70°, and the annual range is 12° to 16°. As is characteristic of marine climates, the warmest weather is delayed until late summer, and February, which has an average temperature of 73° to 77°, is the warmest month. The coolest month, which averages 58° to 64°, is June or July. There are no cold waves, and killing frosts are practically unknown on the coastal plain, which has, in fact, an almost tropical climate. Severe radiation frosts are common over the interior terraces, however, and may occur at any time of the year. Occasional hot dry winds from the interior reach the lower plateaus, but they very rarely extend to the coast. In the following table temperatures at Durban are compared with those at four other cities, each near latitude 30° N. or S. and each (except Calcutta) on the east coast of a continent. All the cities other than Calcutta

	Mean Annual Temp.	*Temp. of Warmest Month*	*Temp. of Coldest Month*	*Annual Range of Temp.*
Durban, S. Africa	70.5	76.8	64.3	12.5
Jacksonville, Fla.	69.3	82.1	55.4	26.7
Porto Alegre, Brazil	66.9	76.5	56.3	20.2
Calcutta, India	77.9	82.6	65.2	17.4
Shanghai, China	60.4	80.4	37.8	42.6

are cooler than Durban in the coolest month and in the annual mean; all except Porto Alegre are warmer in summer, and all have greater ranges than Durban. Three different major types of climate are represented: tropical at Calcutta, intermediate at Shanghai, and subtropical at the other stations.

The rainfall regime of the South African coast is similar to that of the humid subtropical province of the United States. The maximum occurs in summer, but all months have some rain. The

annual amounts, however, average ten to fifteen inches less in Africa than in the United States. During the summer half-year, October–March, the inflowing, onshore winds are stronger and more nearly constant because of low pressure in the interior of the continent south of the equator. Also, convection is more active at this season. These conditions account for the greater rainfall in summer. In the winter half-year, April–September, easterly winds

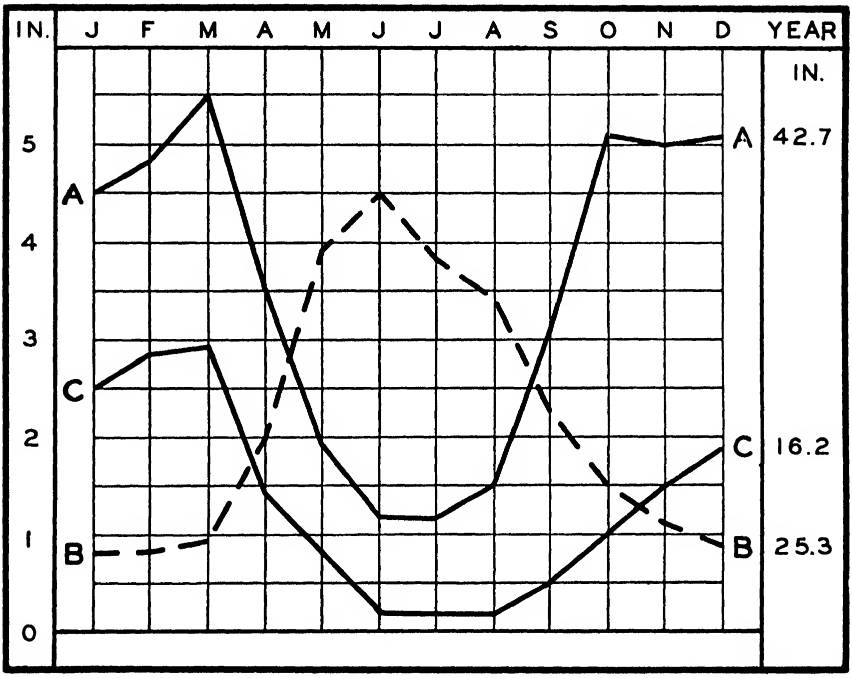

FIG. 98—Average Precipitation. Subtropical climates of South Africa.
A. Durban (STH). B. Capetown (STM). C. Kimberley (STS).

continue to prevail along most of the coast, but they are weaker and subject to more interruptions, for there is moderately high pressure over the high veld and a tendency to outflowing and descending air. The concentration of the rainfall in the summer months is greatest in the northern portion of the belt; at the southern end there is little difference between winter and summer amounts of rainfall.

On the coastal plain there is a native growth of palms, mangroves, and wild bananas, and cultivated crops include tea, coffee, cotton, rice, and sugar cane. These plants attest to the subtropical

character of the climate and to the infrequency of frosts. On the lower terraces, where the rainfall is lighter than on the plain, wheat, oats, and corn are grown, and there is much grazing land.

The Mediterranean Climate of Southern Africa (STM)

The extreme south of Africa from Port Elizabeth to Capetown consists, as does southeast Africa, of a narrow coastal plain succeeded by a series of terraces parallel to the shore. Here also the climate is subtropical, but the type changes from the humid subtropical to the Mediterranean type (STM), which is marked principally by a smaller rainfall and a winter maximum. Temperatures are slightly lower all year than on the southeast coast, because they are less influenced by the Mozambique Current and more subject to the influence of the eastward drift of cool water which is induced by the prevailing westerlies.

The temperatures correspond rather closely to those at San Diego, California, and are slightly higher during both winter and summer than are those at Valparaiso, Chile. The south African coast is definitely cooler in summer and warmer in winter than are the typical Mediterranean lands of Europe, which are at a considerably higher latitude. The climate is warm subtropical and strongly marine, with no large extremes of temperature and without frosts on the lowlands. On the terraces the days are hot, the nights are cool, and frosts sometimes occur.

In summer the region is near the center of the subtropical belt of dry descending air, light southerly winds prevail (corresponding to northerly in the Northern Hemisphere), and there is little rain. In winter the high pressure belt moves north of the region, and west and northwest winds are frequent. The region comes under the occasional influence of the traveling barometric depressions of the prevailing westerlies, and most of the rain falls in connection with the passage of these storms, as is the case in other Mediterranean climatic provinces. Heavy rains of short duration and sometimes high winds occur as these storms pass. The extreme southern point, Cape Agulhas, is often stormy.

The annual rainfall is mostly between twenty and twenty-five inches, but along the west coast northward from Capetown the amount decreases rapidly as climatic conditions merge into those of the small strip of steppe which extends to the coast and which

separates the Mediterranean region from the coastal desert. At Capetown 77% of the rain falls in the winter half-year, April–September; at Port Elizabeth only 54% falls during these months. The latter marks the transition between the type with winter maximum and that with summer maximum.

The products of the coastal plain are typical of the Mediterranean type of climate. Grape-growing is an important industry, and among the fruits grown are olives, oranges, apricots, peaches, and apples. The uplands are mostly pasture lands which support many cattle, sheep, goats, and horses. There are also ostrich farms on the plateaus.

CHAPTER XXIII

Climates of Australia and New Zealand

Australia, a continent lying wholly in the Southern Hemisphere, is roughly oval in shape and compact, having few indentations and a short coast line in relation to its area, which is practically the same as that of the United States. It is approximately bisected by the Tropic of Capricorn, and its latitudinal position, 11° S. to 39° S., is similar to that of South Africa and the middle portion of South America. In the Northern Hemisphere, corresponding latitudes include the Sudan and the Sahara, and in North America include Mexico and the southern third of the United States. The principal mountain system of Australia extends along the entire east coast. Low mountain ranges, which surround most of the rest of the continent, are separated from the coast by narrow plains twenty to 100 miles in width. The remainder of the continent is mainly a huge plateau of moderate elevation, 600–1,500 feet, but there is a large lowland area in the southeastern quarter.

New Zealand consists of two elongated islands trending southwest-northeast, between latitudes 35° S. and 46° S., and lying about 1,200 miles southeast of southeastern Australia. The latitude is that of Argentina from Buenos Aires to the Gulf of St. George, and it corresponds in the Northern Hemisphere to the latitude of the Mediterranean area, and to that of the west coast of the United States from Santa Barbara to Portland.

The ocean waters around Australia are mainly warm waters of tropical origin. A part of the south Equatorial Drift turns southward along the east coast of Australia, and a part continues westward along the north and northwest coasts. The south coast receives some cold water from the eastward drift in the prevailing westerlies, but there is no well-developed cold current. There is no strong contrast in water temperatures such as occurs on opposite sides of South Africa and South America in corresponding latitudes. In New Zealand the northern portion of North Island is in

the equatorial drift; South Island is in the west wind drift. Australia has considerable uniformity of climate; only five climatic types are represented as compared with nine in the United States. All of New Zealand is included in one climatic province.

General Features of Australian Climate

Australia lies mainly in the subtropical high pressure belt and in the belt of the southeast trade winds. In summer (January) the ridge of high pressure and subsiding air lies just south of the southern coast, and there are centers of maximum pressure both east and west of the continent, one in the Indian Ocean and one in the South Pacific. At this season the doldrums lie along the north coast, and have their center of low pressure over the northwest coastal area and the Timor Sea, which is shallow and unusually warm for an ocean surface. Hence, there are inflowing winds on all sides of Australia in summer, as the air moves from the centers of high pressure to the center of low pressure and the heated interior.

In winter (July) the belt of high pressure overlies the entire southern half of the continent, with the central ridge near the Tropic of Capricorn. The region north of the tropic, therefore, has outflowing, southeast trades moving toward the equator, and the south portion has mostly outflowing, northwesterly winds. Exceptions occur in the southwest peninsula and in the west part of the southeast peninsula. These have southwesterly winds under the influence of the westerlies, which approach the southern coast at this season. Because of its latitude and its position relative to the general circulation, as just described, Australia has tropical and subtropical types of climate, and much the greater part of it is arid or semiarid. There is orographic rain where steady winds move upslope over mountain systems; there is convective rain of equatorial type in the extreme north in summer, and there is cyclonic rain from the westerlies in the south in winter. One-third of the continent, however, has less than ten inches a year.

Northern Australia is in the latitude in which tropical cyclones occur. A number of such storms, corresponding to the typhoons of the Philippines and the China Sea, originate in the vicinity of Samoa and the Fiji Islands and move westward. They usually recurve to the southeast, deflected by the earth's rotation, before

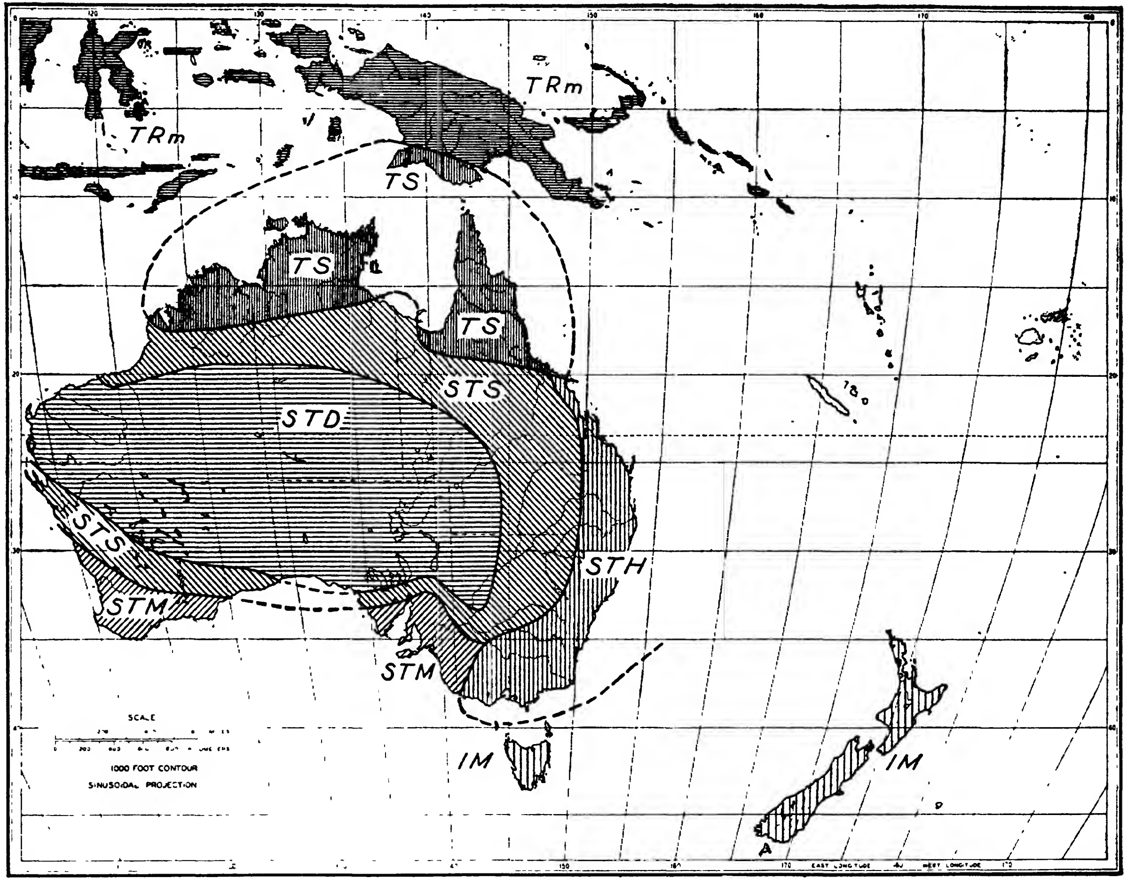

FIG. 99—Climates of Australia and New Zealand.

TRm—Tropical Rainy (monsoon subtype).

TS—Tropical Savanna.

STS—Low Latitude Steppe.

STD—Low Latitude Desert.

STH—Humid Subtropical.

STM—Mediterranean.

IM—Humid Marine.

(Base map by permission of the University of Chicago Press.)

reaching Australia, but an occasional storm of this character does much damage and causes excessive rain in northeast Australia, especially on the Queensland coast. Other similar storms originate in the Timor Sea and move along the northwest coast with destructive force. These curve inland over the southwestern steppe and desert region with decreasing violence, and are welcome because of the valuable moisture they contribute. These storms correspond in position to those that occur west of Mexico. Only in these two regions are tropical cyclones found on the west coasts of continents.

Except for the large arid areas and a few small well-watered coastal areas, Australia is essentially a pastoral continent. The characteristic native trees of Australia are the eucalyptus trees, of which there are 150 species. They cover the coastal strip and the hillsides, and are somewhat drought-resistant, but they are replaced in the drier steppes by acacias, of which there are also a great many varieties. Both the eucalypts and the acacias are a faded grayish-green in color. Although Australia's plants (except for the grasses) are of the class known as *evergreens,* the landscape is never of the bright green color common in most other parts of the world.

Tropical Savannas of Northern Australia (TS)

The truly tropical portion of Australia includes the two northern peninsulas, the east coastal region southward to latitude 20° S., and the northwest coast to latitude 18° S. These regions are typical, sparsely timbered, tropical grasslands with high temperatures all year and with distinct wet and dry seasons.

Temperature

The mean annual temperatures in most of this area are above 80°. The average of the coldest month is above 70°, and that of the warmest month is above 85°. The annual ranges are less than 10° in coastal situations, and between 10° and 20° in the interior. Humidity is rather high even in the dry season, and eight to ten months have wet-bulb temperatures above 70°. This means that the sensible temperature is high and that the climate is enervating and debilitating. Wyndham on the north coast has two months, November and December, with mean temperatures of 90°, and

these months have moderate rainfall and high humidity. Northwest Australia is one of the hottest humid-climate regions of the world. The extreme north, as exemplified by Cape York and Darwin, is nearer the equator, but is not quite so hot, especially in summer. It is subject to more marine and less continental influence, but all months average above 75°, and the hottest months have mean temperatures of 81° to 86°.

Rainfall

Heavy rain, amounting to fifty to eighty inches a year, falls in the northern parts of the two peninsulas and on the east coast of the Cape York Peninsula. The amount decreases to about twenty-five inches in the interior of the savanna region and on the west

Humid Climates of Australia	*Elevation (Feet)*	*Temperature, °F.*				*Precipitation (Inches)*		
		Year	*Coolest Month*	*Warmest Month*	*Annual Range*	*Year*	*Wettest Month*	*Driest Month*
TS								
Cape York	70	79.3	Aug. 76.1	Dec. 81.7	5.6	82.0	Jan. 22.9	Sept. 0.1
Darwin	100	82.6	July 77.4	Nov. 85.8	8.4	61.8	Jan. 15.9	July 0.1
Daly Waters	700	80 4	July 68 6	Nov. 88.3	19.7	26.9	Feb. 6.7	July 0.1
Wyndham	25	84.9	July 75.7	Nov. 90.1	14.4	28.4	Jan. 9.7	Aug. 0
STH								
Brisbane	135	68.9	July 58.5	Jan. 77.2	18.7	44.7	Jan. 6.3	Aug. 2.1
Port Macquarie	50	64 4	July 54.5	Jan. 73.0	18.5	61.5	Feb. 7.5	Oct. 3.2
Sydney	145	63.0	July 52.3	Jan. 71.6	19.3	47.9	Apr. 5.6	Nov. 2.8
Melbourne	115	58.3	July 48.5	Jan. 67.5	19.0	25.6	Apr. 2.3	Feb. 1.8
STM								
Adelaide	140	62.9	July 51.5	Jan. 74.2	22.7	21.2	June 3.1	Jan. 0.7
Geraldton	15	66.5	July 58.6	Feb. 75.0	16.4	17.8	June 4.6	Dec. 0.1
Perth	195	64.0	July 55.0	Feb. 74.1	19.1	33.3	June 6.6	Jan. 0.3

coast. Almost all of it falls in the seven months, October–April, and in some places in a shorter season of four to six months, beginning in November or December. This is the season when the equatorial belt of low pressure overlies northern Australia, and there are inflowing monsoonal winds and rising air. The winds are northeast on the east coast, northerly on the north coast, and westerly on the west coast. The rains begin with thundershowers in October or November, but as the monsoon becomes well-established the rain increases until, for the period from December–

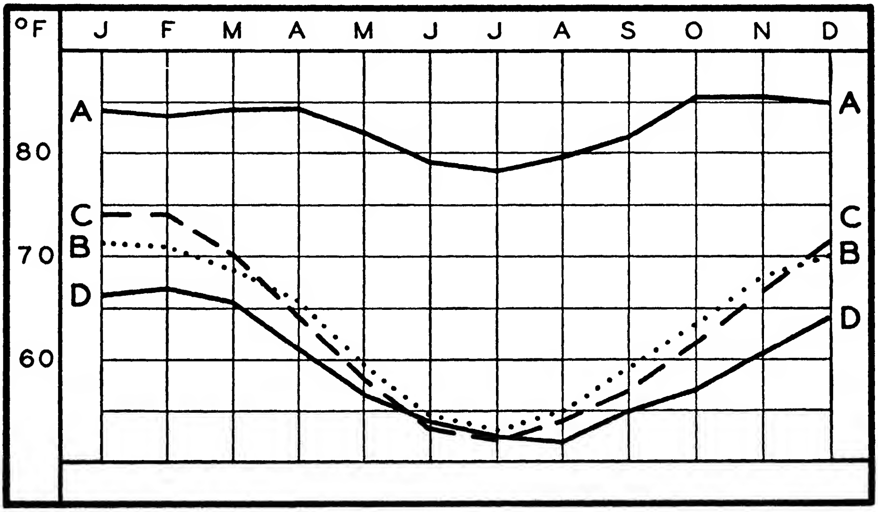

Fig. 100—Average Temperature. Climates of Australia and New Zealand.
A. Darwin (TS). C. Adelaide (STM).
B. Sydney (STH). D. Aukland (IM).

March, the sky is almost continuously overcast and there is rain almost every day. A maximum falls in January or February. With the coming of autumn the pressure trough retreats northward, high pressure covers the center of the continent, the winds change to dry southeasterly trades, and the rainfall declines rapidly. Rainfall is moderate to light in April and May and almost negligible in the winter months, June–September, except on the east coast in the southern half of the savanna province. Here the southeast winds make a forced rise over the mountains, and there is rain in all months.

Because of the long dry season of four or five months, and in spite of the large annual rainfall in the coastal regions, there are no tropical forests or jungles, but only scattered eucalypts and

acacias. The rainfall is less useful than half the amount would be with a better distribution. Some sugar cane is grown where water is available, but the principal occupation is cattle raising.

The Humid Subtropical Climate of Eastern Australia (STH)

The east coast of Australia from latitude 20° south to the southern end of the continent has a humid subtropical climate. This province includes the coastal plain and the eastward-sloping highlands of the Great Dividing Range in the states of Queensland, New South Wales, and Victoria. The climate is of the same type as that of the east Gulf Region of the United States, but is strongly marine and resembles the climate of Florida more than that of the other Gulf states.

Temperature

The coastal part of this province is notable for its equable temperature. Brisbane has about the same mean annual temperature as Jacksonville and New Orleans, but its summers are 5° cooler and its winters 4°–5° warmer. Brisbane has an annual range of 19°, Jacksonville, 27°, and New Orleans, 28°. Sydney's annual mean temperature is like that of Atlanta, but its annual range is 19° whereas Atlanta's is 35°. Sydney lacks both the cold winters and the hot summers of Atlanta. This coast is free of frost as far south as Sydney, where the minimum temperature of record is 35°. Even at Melbourne, in the latitude of Richmond, Virginia, the absolute minimum is 27°. Indeed, the entire coast has a mild and equable subtropical climate which is not uncomfortable at any season of the year, although temperatures above 100° do occur occasionally when hot descending winds from the interior reach the coast. As far south as Sydney the coast is tropical in respect to the complete absence of frosts, but not with reference to its mean monthly temperatures. Four winter months have mean temperatures below 65°. In the interior with increasing elevation there is an increasing range of temperature, and hard freezes are not uncommon.

Rainfall

The rainfall of the region is largely orographic, brought by the forced ascent of the trade winds. It is heaviest on the Queensland coast, where it amounts to more than fifty inches a year, and,

in places, to more than 100 inches. In the rest of the humid subtropical province the annual total is between thirty and fifty inches. There is rain in all months, but in the northern portion there is a distinct maximum in summer, December–March. Far-

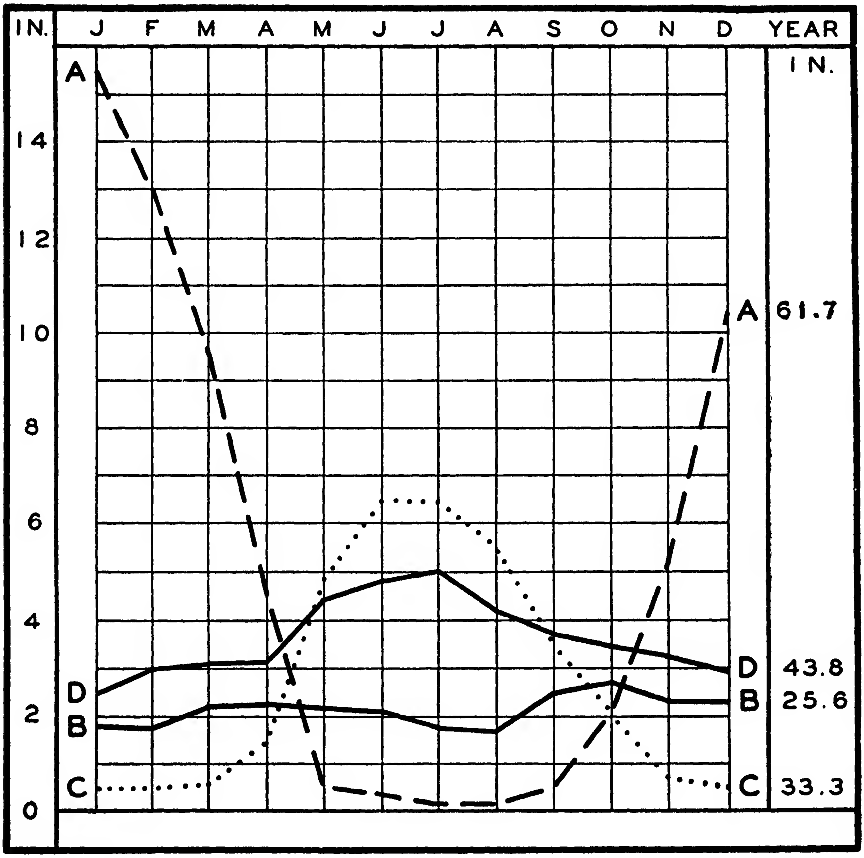

Fig. 101—Average Precipitation. Climates of Australia and New Zealand.
A. Darwin (TS). C. Perth (STM).
B. Melbourne (STH). D. Aukland (IM).

ther south there is a more even distribution with a tendency to an autumn (April and May) maximum, but with considerable local variation influenced by relief. The entire region is subject to excessive rains, and amounts of more than twenty inches in twenty-four hours have been recorded.

Sugar cane is grown extensively in wet coastal situations, grapes are grown in New South Wales and Victoria, and oranges flourish to the southern extremity of the continent. In the inte-

rior, where the rainfall is thirty to forty inches, corn and wheat are produced, and dairying, cattle raising, and sheep raising are important industries.

The Mediterranean Climate of Australia (STM)

Two small areas in southern Australia have a subtropical climate of the Mediterranean type. One of these areas is situated in western Victoria and the southeast portion of the State of South Australia. The other is in extreme southwestern Australia. These areas do not differ materially in temperature from the humid subtropical region just described, but the rainfall regime is quite distinct. There is a marked maximum in winter and a minimum in summer that amounts in some cases to an almost rainless period of two or three months. They differ from the east coast also in having a smaller annual total rainfall. As in other regions with a Mediterranean type of climate, they are under the influence of the subtropical high in summer and of the prevailing westerlies and their cyclonic storms in winter. They are westward-facing slopes, and the easterly winds are descending and, therefore, dry winds.

Temperatures at Adelaide and at Perth are very similar to those at Los Angeles, Palermo, Gibraltar, and Capetown. Summers are moderately hot, but the afternoon heat is tempered by sea breezes. The warmest month has a mean of about 74°. Winters are mild; the coldest month averages 51°–55°, and freezing temperatures are rare. Adelaide has a record minimum of 23°, as compared with 28° at Los Angeles and with 25° at San Diego. On the west coast even light frosts are rare as far south as Perth. There are occasional hot, dry, dusty winds from the interior desert in the warm sector of a traveling depression, as is the case also on the east coast. After the passage of the cold front on the westerly side of the depression, the hot winds are often succeeded by blustery, cold winds locally called *Southerly Bursters*. These are similar to the *Pamperos* of Argentina.

The rainfall averages twenty to forty inches a year. It is heaviest near the coast, and decreases inland and northward. At Adelaide 70% of the annual total falls in the winter half-year, and each of four summer months receives one inch or less. In the southwestern region the percentage falling in the winter half of the year is eighty-five to ninety, and there are five or six summer

months averaging less than an inch. The typical crops of the Mediterranean type of climate are found in these Australian representatives of the type. Olives and grapes are grown extensively in both areas. There are also oranges, and on the almost frostless west coast there are pineapples and bananas. The interior areas with more than fifteen inches of winter rain are well-adapted to the production of winter wheat, as are similar regions in California. Large areas are devoted to pastoral pursuits.

The Australian Steppe Climate (STS)

Bordering the three humid types of climate that have been described, a broad semiarid ring almost encircles the continent, omitting only the central portion of the west coast and a small part of the south coast in the Great Australian Bight. The broadest parts of this subtropical steppe are the northern strip reaching from the west coast between latitudes 18° and 20° eastward to the Gulf of Carpentaria, and the eastern strip extending southward to include a large part of interior Queensland and New South Wales. There are narrower strips in the southeast and southwest of the continent.

The northern strip has mean annual temperatures between 75° and 80°. The temperature of the coolest month is above 65°, and that of the warmest month is above 85°. The conditions are tropical, except that large diurnal ranges result in occasional frosts at night. Rainfall amounts to ten to twenty-five inches a year. It is largely concentrated in four summer months; there is large variability in the annual amount, and evaporation is high. For these reasons the rainfall effectiveness is small. The region is thinly inhabited and not well-suited to white habitation. Vegetation is largely low acacia scrub interspersed with enough grass to support a few cattle.

In much of the eastern belt of steppe, the rainfall distribution is better than in the north, temperatures and evaporation are lower, and agricultural and living conditions are more favorable. Here the annual temperatures average 65° to 75°, with two to five months below 65° and with one or two months below 55° in most of the area. Frosts are frequent. The annual rainfall is ten to twenty inches, with a maximum in summer in the northeast, changing to a winter maximum in the south. The annual variability is large. In parts of this region in Queensland and New South Wales

there are eucalyptus trees and a good cover of grasses, and here there are large herds of cattle and sheep. From the beginning of settlement sheep-raising has been one of the major industries of Australia. The greatest numbers of sheep are in the interior portions of New South Wales, Queensland, and Victoria where the rainfall is between ten and thirty inches—that is, in the steppe and in the drier portions of the humid subtropical provinces. Large numbers of cattle are also raised in the eastern steppe, especially in northern Queensland.

Dry Climates of Australia	*Elevation (Feet)*	*Temperature, °F.*				*Precipitation (Inches)*		
		Year	*Coolest Month*	*Warmest Month*	*Annual Range*	*Year*	*Wettest Month*	*Driest Month*
STS								
Broome	65	79 8	July 70.3	Jan. 85 9	15 6	23 0	Feb. 6 4	Aug. 0
Cloncurry	695	76.9	July 61.3	Dec. 88 0	26.7	20 0	Jan. 5 1	Aug. 0.1
Charleville	975	68.4	July 51.0	Jan. 82.8	31.8	20.6	Feb. 3 3	Aug. 0 6
Bourke	460	68.5	July 51.4	Jan. 84.2	32 8	15.2	Jan. 2 0	July 0.9
Coolgardie	1389	64.4	July 50 8	Jan. 77 3	26.5	9.2	May 1.3	Jan. 0.4
STD								
Alice Springs	2000	69 6	July 52.6	Jan. 83.3	30 7	11.1	Jan. 1.8	Aug. 0.4
William Creek	250	68 4	July 52.2	Jan. 82.7	30.5	5.4	March 0.8	Aug. 0.3
Onslow	15	75 4	July 63 7	Feb. 85.3	21 6	7.2	June 1.8	Sept.–Nov. 0
Nullagine	1265	76.4	July 59.3	Jan. 89 8	30 5	12 7	Jan. 2.7	Sept.–Oct. 0
Eucla	30	63.5	July 54.3	Feb. 71.1	16.8	10.1	May 1.2	Dec. 0.4

The southwestern semiarid strip which separates the Mediterranean province from the desert is subject to some marine influence. This influence shows especially in the mean summer temperatures, the mean of the hottest month being only 75°–77°. There are six months with mean temperatures below 65°. The an-

nual rainfall, like that of the adjoining interior portion of the Mediterranean province, is ten to eighteen inches. There are stunted drought-resistant eucalypts in the region, and there is enough pasturage to support a considerable number of sheep, especially in the cooler half of the year.

The Australian Desert (STD)

The remainder of Australia, amounting to about 40% of its total area, is low-latitude desert. The desert includes the central and western interior of the continent, and extends to the ocean on the middle west coast and also for a short distance on the south coast in the Great Australian Bight. It is larger than any desert area of the world, except the Sahara Desert, which is about three times as large. The position of the Australian desert corresponds to that of most of the other great deserts—that is, it is in the region of the trade winds and the subtropical high pressure belts. These trade wind and high pressure belts all lie mainly between latitudes 20° and 30° north or south. Its aridity is intensified by the existence of a mountain chain along the eastern coast. These mountains intercept the trade winds and rob them of much of their moisture, with the result that the trades move across central and western Australia as dry and subsiding winds.

The arid region lies between the northern steppes and savannas, which have tropical summer rains, and the southern coastal regions which receive winter rains from the storms of the westerlies. Hence the northern part of the desert receives most of its scanty rainfall in summer, and the southern part in winter. Occasional troughs of low pressure extend into the interior, attended by showers and thunderstorms and sometimes by general rains. Most of the desert thus receives some rain in all months, but part of the west coastal area is entirely without rain for two or three months in spring (September, October, and November). Irregularities of elevation result in local differences in the amount of rainfall; the lowest portion is in the southeast around Lake Eyre, and in this region the rain amounts to about four inches a year. In some hilly situations as much as ten to fifteen inches fall on the average. As is usual in desert climates, much of the rain falls in heavy showers at long intervals, and there is great variability in the annual amounts.

High temperatures occur throughout the desert. Maxima above 120° have been observed, and temperatures above 100° often occur for many days in succession. The western portion is the hottest, and a considerable area has a mean temperature of 90° for the months of December and January. The desert cools rapidly in winter, and the July means are between 50° and 65°. The annual ranges of temperature are mainly between 16° and 30°. The air also cools rapidly at night. Even in summer the nights are cool, and during the low-sun months freezing temperatures due to radiation cooling occur throughout the desert except in the extreme north and on the west coast. Temperatures as low as 25° occur frequently at Alice Springs at an elevation of 2,000 feet on the Tropic of Capricorn.

The margins of the desert afford some pasturage for sheep and cattle, but the greater part of the region is almost uninhabited except where mining operations support a local population. Desert conditions with reference both to heat and aridity are not much less severe than in the heart of the Sahara.

The Humid Marine Climate of Tasmania and New Zealand (IM)

The island of Tasmania (latitude 41°–43° south) at the southeastern extremity of Australia, and the two islands that constitute New Zealand (latitude 35°–46° south) are mostly within the prevailing westerlies throughout the year. They are comparatively narrow in an east-west direction, and are broadside to the westerly winds. They therefore have a markedly marine climate which is practically free from continental influences. The climate is of the same type as that of the British Isles and the west coast of the United States from Eureka to Seattle. It is an intermediate, humid marine climate, although the greater part of the region has a shorter cool period with mean temperatures below 50° than is characteristic of the type.

Tasmania

In Tasmania the mean temperatures much resemble those of Seattle and Valencia, Ireland. The annual mean is 52°–56°; the mean of the coldest month is about 45°, and that of the warmest month is about 60°. Irregular changes of temperature are slight; there are no cold waves or hot spells. At Hobart the absolute

minimum of record is 27°; Seattle has recorded a minimum of 3° and has had temperatures below 27° in each month from November to March, inclusive. Hobart has nine months with mean temperatures above 50°, and Seattle and Valencia, six each. This is partly a latitude effect, since Hobart is 5° nearer the equator than Seattle and 9° nearer than Valencia.

A mountain ridge of moderate elevation, 3,000–5,000 feet, divides the island into east and west sides. Since westerly winds prevail all year, the west side is the wet, windward side, and the east side is drier. But traveling depressions occur at all seasons and are attended by shifting winds as the fronts move eastward, and they therefore give rain on both sides of the mountains. The rainfall maximum is in winter and spring, when the depressions are most active, and the minimum is in summer, but the annual amount is less and the distribution more even than on the coast of Oregon and Washington. In the western district the general average rainfall is about thirty-eight inches a year, in the eastern district about twenty-two inches. The annual amount is more than 100 inches at places on the windward slopes of the mountains. Snow is rare except at the higher elevations. Grasses remain green all year, and Tasmania is well-adapted to grazing, especially sheep-raising. Wheat and oats are grown in considerable quantity, as are such fruits as apples, pears, apricots, and peaches.

New Zealand

Like Tasmania, the greater part of New Zealand is continuously within the flow of the westerly winds and has a succession of cyclonic disturbances at all seasons, resulting in a moist, west-coast marine climate (IM). Because it extends through 11° of latitude and because it has some high and continuous mountain ridges, it has a considerable variety of climate within this type. The two islands into which the country is divided will be considered separately.

South Island. The southern island of New Zealand, which lies wholly within the belt of the west winds, has a high and rather broad series of mountain ranges traversing it from end to end, without important gaps and with peaks rising to 12,000 feet. These mountains are an effective climatic divide. The entire west side of South Island is wet, cloudy, and chilly. Clouds hang on

the mountains and vegetation drips with water much of the time. This west coast is clothed with luxuriant evergreen grasses and forests, and it much resembles the west coast of southern Ireland. Like Ireland it has no severe freezing weather, but, on the other hand, it has few warm, sunny days. Again, like Ireland, it has frequent gales. The annual rainfall exceeds 100 inches and is well distributed. At Hokitika only one month averages less than nine inches, and none averages more than twelve inches. On the eastern side the average rainfall in most of the settled district is thirty to fifty inches, but some of the plains in the lee of the mountains have only twenty to twenty-five inches. There is ample sunshine, and the air is clear and invigorating.

Intermediate Marine (IM) Climate of Tasmania and New Zealand	*Elevation (Feet)*	*Temperature, °F.*				*Precipitation (Inches)*		
		Year	*Coolest Month*	*Warmest Month*	*Annual Range*	*Year*	*Wettest Month*	*Driest Month*
Tasmania								
Hobart	160	54.3	July 45.7	Feb. 62.2	16.5	23.6	Nov. 2.5	Feb. 1.5
New Zealand								
Auckland	260	59.1	July 51.7	Feb. 67.0	15.3	43.9	July 5.0	Jan. 2.7
Wellington	140	55.2	July 47.5	Jan. 62.4	14.9	41.1	July 4.7	Feb. 2.7
Hokitika	15	....	....	....	....	116.5	Oct. 11.9	Feb. 7.2
Dunedin	500	50.5	July 42.4	Jan. 57.7	15.3	25.2	July 2.8	Oct. 1.6

The mean monthly and annual temperatures are much the same on the two sides of the Island. The range is from about 42° in July to 58° in January. These temperatures are similar to the temperatures of Tasmania and Valencia. Although the winters are mild for the latitude, freezing temperatures occur throughout the Island. The original vegetative cover was mainly evergreen forest on the western slopes and grasses on the eastern slopes. The Island is well-suited for the grazing of sheep and cattle and for dairy farming. The chief exports are wool, dairy products, and frozen meats.

North Island. North Island has a lower and less continuous mountain system, and is less distinctly divided into eastern and western districts. It approaches the equatorward limit of the westerly winds, and the northern peninsula of the Island has much east wind in summer out of the Pacific subtropical high. In some respects temperature conditions in North Island approach subtropical, and parts of the Island might be so classified. Both annual and diurnal ranges of temperature are smaller, however, than in most subtropical climates. At Auckland all months have mean temperatures above 50°, but only two months average warmer than 65°. Maximum temperatures seldom exceed 85°, and minimum temperatures near the coasts are above 32° during most winters, but lower in the interior. Frosts are so infrequent along the coasts as to permit the growth of oranges and lemons. Wellington, at the southern end of the Island, has three months with temperatures slightly below 50° and none over 63°. Winters in North Island are similar to those in southern Italy; summers are 10° cooler.

Rainfall is rather evenly distributed seasonally, but a maximum occurs in the winter months, May, June, and July, when the Island is more completely exposed to the storms of the westerlies. The least rain occurs in summer, December, January, and February, which is the season when the westerlies recede southward. Annual amounts are generally between forty and fifty inches, but reach seventy-five inches on the higher mountain slopes. North Island not only produces citrus fruits, but it also produces grapes, apples, pears, and other fruits. The Island is, however, chiefly devoted to stock-raising and dairying.

APPENDIX I

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APPENDIX II

Mean Monthly and Annual Temperatures and Rainfall

(T. = temperatures in degrees Fahrenheit. Rf. = rainfall in inches.)

TROPICAL RAINY CLIMATES (TR)

Station		*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Annual*
North America														
Key West,	T.	70	71	73	76	79	82	84	84	82	79	74	70	77
Florida	Rf.	2.0	1.5	1.5	1.3	3.3	4.5	3.5	4.8	6.4	5.6	2.0	1.8	38.0
Santiago	T.	75	75	77	78	80	81	82	82	81	80	78	76	79
de Cuba	Rf.	1.4	0.9	1.7	3.3	6.3	5.5	2.2	3.5	6.7	7.3	3.7	1.1	43.8
South America														
Iquitos,	T.	78	78	76	77	76	74	74	75	76	77	78	78	77
Peru	Rf.	10.0	10.6	12.0	6.6	9.8	7.3	6.5	4.6	8.8	7.1	8.5	11.3	103.3
Para,	T.	78	77	78	78	79	79	78	79	79	79	80	79	78
Brazil	Rf.	12.5	14.1	14.1	12.6	10.2	6.7	5.9	4.5	3.5	3.4	2.6	6.1	96.2
Eurasia														
Akyab,	T.	70	73	79	83	84	82	81	81	82	82	78	72	79
India	Rf.	0.1	0.2	0.5	2.0	13.7	49.4	53.7	42.5	24.6	11.6	5.0	0.6	203.8
Nhatrang,	T.	75	77	79	82	83	84	84	84	82	80	78	76	80
Indo-China	Rf.	2.4	1.1	0.9	0.9	2.4	2.2	2.0	1.5	6.9	10.6	13.9	9.6	54.4
Pontianak,	T.	78	79	79	79	80	80	80	79	79	79	78	78	79
Borneo	Rf.	10.8	7.9	9.8	10.8	10.7	8.7	6.3	8.9	8.4	14.8	15.7	13.2	125.9
Menado,	T.	77	77	78	78	79	79	79	80	80	79	79	78	79
Celebes	Rf.	18.6	14.4	10.3	8.0	6.6	6.5	4.9	3.8	3.4	4.8	8.6	14.7	104.6
Africa														
Douala,	T.	80	80	80	79	79	77	75	75	76	76	78	79	78
Fr. Eq. Africa	Rf.	1.9	3.7	8.0	8.9	12.0	21.5	29.3	27.2	20.7	16.9	6.3	2.6	159.0
Luluaburg,	T.	76	76	76	77	77	76	77	76	76	76	77	77	77
Belgian Congo	Rf.	7.2	5.4	7.9	6.1	3.1	0.2	0.1	2.5	6.5	6.6	9.1	6.6	60.8

TROPICAL SAVANNA CLIMATE (TS)

Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
North America														
Port au Prince,	T.	76	77	78	79	80	81	82	81	81	80	78	77	79
Haiti	Rf.	1.2	2.5	3.7	6.5	9.4	4.1	2.7	5.4	7.3	6.6	3.4	1.3	54.1
South America														
Caracas,	T.	65	65	66	68	70	69	68	68	69	68	67	65	67
Venezuela	Rf.	0.9	0.3	0 6	1.6	2 8	4.0	4.3	4.2	4.1	3.8	3.3	1.8	31.7
Cuyaba,	T.	81	81	81	80	78	75	76	78	82	82	82	81	80
Brazil	Rf.	9 8	8.3	8 3	4.0	2.1	0.3	0.2	1.1	2.0	4.5	5.9	8.1	54.6
Eurasia														
Bangalore,	T.	69	73	78	82	80	76	74	74	74	74	71	69	74
India	Rf.	0.2	0.2	0.5	1.3	4.7	3.1	4 0	5.6	6.8	6.0	2.2	0.6	35.3
Saigon,	T.	79	81	84	86	84	82	82	82	82	81	80	79	82
Indo-China	Rf.	0 9	0.1	0 3	1.7	8 3	12.6	11.1	11.0	13.3	11 1	3.7	3.1	77.2
Africa														
Bathurst,	T.	74	75	76	76	77	80	80	79	80	81	79	75	78
Gambia	Rf.	0	0	0	0	0.2	2.9	10.9	19.6	10.0	3.7	0.2	0.1	47.6
Mongalla,	T.	80	82	83	81	79	77	76	76	77	78	79	79	79
Sudan	Rf.	0.1	0.8	1.5	4.2	5.4	4.6	5.2	5.8	4.9	4.3	1.8	0.3	38.9
Entebbe,	T.	71	71	71	70	70	69	69	69	69	70	70	70	70
Uganda	Rf.	2.6	3.6	5.8	9 8	8 5	5.1	3.0	3.0	3.1	3.5	4 9	5.1	58 0
Zanzibar,	T.	83	83	83	81	79	78	77	77	78	79	81	83	80
Tanganyika	Rf.	2.8	2.2	6.1	14 1	10.7	2 0	2 4	1.7	2.1	3.6	7.5	5.4	60.2
Australia														
Darwin,	T.	84	83	84	84	82	79	77	80	83	86	86	85	83
N'ern Ter.	Rf.	15.3	13.0	9.7	4.5	0.7	0.2	0.1	0.1	0 5	2.1	5.2	10.3	61.7
Cairns,	T.	82	81	80	77	74	71	70	70	73	76	79	81	76
Queensland	Rf.	15.8	16.4	17.7	12.1	4.3	2.8	1.6	1.7	1.7	1.8	4.0	8.6	88.5

TROPICAL HIGHLAND CLIMATE (TH)

Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
North America														
Puebla,	T.	54	57	61	64	65	64	63	63	62	61	58	54	61
Mexico	Rf.	0.4	0 3	0.4	1.1	3.5	6.8	5.8	6.0	5.5	2.5	0 9	0.4	33.6
South America														
Quito,	T.	55	54	54	54	55	55	54	55	55	55	54	55	55
Ecuador	Rf.	4.2	4 3	5.2	7.4	5.0	1.5	0 9	1.5	3.0	3.7	3.8	3.8	44.1
Africa														
Nairobi,	T.	64	65	66	65	63	61	59	60	63	66	64	63	63
Kenya	Rf.	1.9	4.2	3.7	8 3	5.2	2.0	0.8	0.9	0.9	2.0	5.8	3.5	39.2
Salisbury,	T.	70	69	68	66	61	57	56	60	66	71	71	70	65
S. Rhodesia	Rf.	7.5	7.4	4.5	1.0	0.5	0	0	0.1	0 3	1 1	3 7	5.8	31.9

LOW LATITUDE STEPPE CLIMATE (STS)

Station		*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Annual*
North America														
Del Rio,	T.	52	56	63	70	77	83	84	85	80	70	60	51	69
Texas	Rf.	0.4	0.8	0.9	1 6	2.3	2.0	2.3	1.4	2.3	2.6	1.3	0.7	18.6
South America														
Maracaibo,	T.	81	81	81	83	83	84	84	84	84	82	81	81	82
Venezuela	Rf.	0	0	0 3	0 5	2.4	1.6	1.4	1.3	3 3	4.3	2 5	0.4	18.0
Eurasia														
Mosul,	T.	40	46	53	61	78	84	90	89	82	71	61	45	67
Irak	Rf.	2.8	2.9	2.4	2.4	0.5	0	0	0	0	0.6	2.8	2.2	16.7
Africa														
Mogadiscio,	T.	77	79	81	82	80	77	75	76	76	77	76	77	78
Italian Somaliland	Rf.	0	0	0	7.0	2.2	3.5	2.0	0.6	0.5	0 7	0.4	0	16.9
Australia														
Broome,	T.	86	85	85	83	76	71	70	73	77	81	85	86	80
W. Australia	Rf.	6.2	6.1	3.8	1.4	0.6	1.0	0.2	0.2	0.1	0	0.9	3.7	24.2
Cloncurry,	T.	87	85	83	78	71	64	61	67	72	83	85	88	77
Queensland	Rf.	5.1	4.9	2.7	0.9	0.4	0.3	0.5	0.1	0.5	0.5	1.1	3.0	20.0

LOW LATITUDE DESERT CLIMATE (STD)

Station		*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Annual*
North America														
Phoenix,	T.	51	55	60	67	75	84	90	88	82	70	59	52	70
Arizona	Rf.	0.8	0 8	0.7	0.4	0.1	0.1	1.0	1.0	0.7	0.4	0.6	0.9	7.5
South America														
Iquique,	T.	71	71	69	65	63	62	60	61	63	64	67	69	66
Chile	Rf.				Practically none.									
Eurasia														
Aden,	T.	76	77	79	83	87	89	88	87	88	84	80	77	83
Arabia	Rf.	0.3	0.2	0.5	0.2	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1	1.9
Karachi,	T.	65	68	75	81	85	87	84	82	82	80	74	67	78
India	Rf.	0.5	0.5	0.4	0.2	0.1	0.9	2 9	1.5	0.5	0	0.1	0.1	7.6
Africa														
Cairo,	T.	55	57	63	70	76	80	82	82	78	74	65	58	70
Egypt	Rf.	0.4	0.2	0.2	0.2	0	0	0	0	0	0	0.1	0.2	1.3
Aswan,	T.	59	63	70	78	85	90	91	90	88	82	72	62	77
Egypt	Rf.				Practically none.									
Walvis Bay,	T.	65	66	66	65	62	60	59	57	58	60	61	64	62
S. W. Africa	Rf.				Practically none.									
Australia														
Alice Springs,	T.	84	82	77	68	60	54	52	58	66	74	80	82	70
N'ern Ter.	Rf.	1.8	1.7	1.3	0.9	0.6	0.6	0.4	0.4	0.4	0.7	0.9	1.3	11.1

HUMID SUBTROPICAL CLIMATE (STH)

Station		*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Annual*
North America														
Montgomery,	T.	49	52	58	65	73	80	82	81	77	66	56	49	66
Alabama	Rf.	5.1	5.5	6.3	4.7	3.9	4.1	4 7	4.0	3.1	2.4	3.5	4.7	52 0
Pensacola,	T.	53	55	61	67	74	79	81	81	78	70	60	54	68
Florida	Rf.	4.0	4.4	4.8	3.9	3.3	4.6	6.6	7.6	5.7	4 1	3 9	4.5	57 4
Savannah,	T.	52	54	60	66	73	79	80	81	77	68	59	52	67
Georgia	Rf.	2.8	3.3	3.4	2.9	3.0	5.6	5 4	7 4	5 8	3 0	2 2	2.9	48.8
South America														
Paraná,	T.	77	77	73	66	59	54	54	57	61	66	72	76	66
Argentina	Rf.	4.4	3.8	3.7	3.8	1.8	0.9	1.0	1.3	1.9	4 4	3.6	4.8	35.4
Buenos Aires,	T.	74	72	69	61	55	50	49	51	55	60	66	71	61
Argentina	Rf.	3 1	2.8	3.9	4.8	2.8	2 0	2.1	2.2	2.9	3 3	4.0	4 0	37 9
Bahia Blanca,	T.	74	72	67	60	53	47	47	49	54	59	66	71	60
Argentina	Rf.	2.0	2 2	2 6	2 2	1 1	0 9	1.0	1.0	1 6	2 3	2 0	2.1	21 0
Eurasia														
Delhi,	T.	58	62	74	86	92	92	86	85	84	78	67	60	77
India	Rf.	1.0	0.6	0.5	0 4	0.7	2.9	7 6	7.0	4.7	0 5	0 1	0.4	26 2
Benares,	T.	60	65	77	87	91	89	84	83	83	78	68	60	77
India	Rf.	0.7	0.6	0 4	0.2	0.6	4 8	12.1	11.6	7.1	2.1	0.2	0.2	40 6
Chungking,	T.	48	50	58	68	74	80	83	86	77	68	59	50	67
China	Rf.	0.7	0.9	1.3	4.0	5.3	6.7	5.3	4 4	5.8	4 6	2.0	0.9	41 9
Foochow,	T.	53	51	62	67	73	78	86	86	81	72	66	57	69
China	Rf.	3.1	2.5	4.8	5.3	4.6	6.0	4.3	8.7	3.0	1.3	0.8	1.3	45.7
Kagoshima,	T.	45	45	51	60	65	71	78	80	75	66	57	48	62
Japan	Rf.	3 5	3.3	6.1	9 1	9 6	13.9	11.2	7.4	8.7	5.1	3.7	3.5	85 1
Africa														
Durban,	T.	76	77	75	71	68	64	64	65	67	69	72	74	70
So. Africa	Rf.	4.6	4.9	5 4	3.4	1.9	1.2	1.2	1.7	3.2	5.1	5 0	5.1	42.7
Australia														
Port Macquarie,	T.	73	73	71	66	61	56	55	57	60	64	68	71	64
New S. Wales	Rf.	5.9	7.5	6.5	5.9	5.6	4.6	4.5	3.8	3.9	3.2	4.1	5.9	61.4

MEDITERRANEAN CLIMATE (STM)

Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
North America														
Stockton,	T.	46	50	54	58	64	70	74	72	69	62	53	46	60
California	Rf.	2.9	2.3	2.1	1.1	0.6	0.1	T	T	0.3	0.6	1.5	2.6	14.1
Monterey,	T.	50	51	54	56	59	61	61	62	62	58	54	51	57
California	Rf.	3.5	2.7	3.0	1.3	0.6	0.1	T	T	0.2	0.7	1.6	3.1	16.7
Santa Barbara,	T.	53	55	56	58	60	62	66	67	66	63	59	55	60
California	Rf.	4.1	3.6	2.9	1.2	0.5	0.1	T	T	0.4	0.8	1.4	3.1	18.0
South America														
Valparaiso,	T.	67	66	65	61	59	56	55	56	58	59	62	64	61
Chile	Rf.	0	0	0.6	0.2	3.5	5.8	4.8	3.2	0.8	0.4	0.1	0.3	19.7
Santiago,	T.	67	66	62	56	51	46	46	48	52	56	61	66	56
Chile	Rf.	0	0.1	0.2	0.6	2.6	3.2	3.2	2.1	1.2	0.5	0.3	0.2	14.2
Eurasia														
Gibraltar	T.	55	56	57	61	65	70	73	75	72	67	60	56	64
	Rf.	5.1	4.2	4.8	2.7	1.7	0.5	0	0.1	1.4	3.3	6.4	5.5	35.7
Rome,	T.	45	47	51	57	64	71	76	76	70	62	53	46	60
Italy	Rf.	3.2	2.7	2.9	2.6	2.2	1.6	0.7	1.0	2.5	5.0	4.4	3.9	32.7
Smyrna,	T.	46	48	53	59	68	75	80	79	72	66	56	49	63
Turkey	Rf.	4.3	3.3	3.2	1.7	1.3	0.6	0.1	0	0.7	1.7	3.6	5.2	25.7
Jerusalem,	T.	44	48	51	59	66	70	73	73	71	67	56	49	61
Palestine	Rf.	6.2	4.6	3.5	1.5	0.3	0	0	0	0	0.4	2.5	5.7	24.7
Africa														
Mogador,	T.	57	59	60	63	65	68	68	68	69	67	63	59	64
Morocco	Rf.	2.2	1.5	2.2	0.7	0.6	0.1	0	0	0.2	1.3	2.4	2.0	13.2
Algiers,	T.	53	55	58	61	66	71	77	78	75	68	62	57	65
Algeria	Rf.	4.2	3.5	3.5	2.3	1.3	0.6	0.1	0.3	1.1	3.1	4.6	5.4	30.0
Port Elizabeth,	T.	69	70	68	65	62	59	58	58	60	62	65	68	64
S. Africa	Rf.	1.2	1.3	1.8	2.0	2.4	1.7	1.9	2.1	2.2	2.1	2.1	1.7	22.5
Australia														
Geraldton,	T.	74	75	73	69	64	60	59	59	61	64	68	72	67
W. Australia	Rf.	0.2	0.2	0.4	1.1	2.6	4.6	3.6	2.9	1.1	0.7	0.3	0.1	17.8

MIDDLE LATITUDE STEPPE CLIMATE (IS)

Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
North America														
Kamloops,	T.	22	27	38	50	58	64	70	68	59	48	36	27	47
Br. Columbia	Rf.	0.9	0.7	0.3	0.4	0.9	1.3	1.1	1.1	1.0	0.6	0.9	1.0	10.3
Rapid City,	T.	22	24	32	45	54	64	71	70	60	48	36	27	46
South Dakota	Rf.	0.4	0.5	1.0	1.9	3.5	3.4	2.5	1.7	1.3	1.0	0.5	0.4	18.1
Pueblo,	T.	31	33	41	50	59	69	74	73	65	52	40	31	52
Colorado	Rf.	0.3	0.6	0.7	1.6	1.6	1.3	2.0	1.8	0.9	0.6	0.4	0.5	12.3
Las Vegas,	T.	33	35	41	48	56	65	69	67	61	50	40	32	50
New Mexico	Rf.	0.4	0.8	0.7	1.1	1.8	1.9	3.7	3.2	1.9	1.1	0.7	0.6	17.9
Eurasia														
Orenburg,	T.	3	6	17	38	58	66	71	67	55	39	24	11	38
U. S. S. R.	Rf.	1.1	0.8	1.0	0.9	1.4	2.0	1.7	1.3	1.3	1.2	1.2	1.2	15.2
Urga,	T.	−16	−4	13	34	48	58	63	59	48	30	8	−7	28
Mongolia	Rf.	0	0.1	0	0	0.3	1.7	2.6	2.1	0.5	0.1	0.1	0.1	7.6

MIDDLE LATITUDE DESERT CLIMATE (ID)

Station		*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept*	*Oct.*	*Nov.*	*Dec.*	*Annual*
North America														
Tonopah,	**T.**	30	34	40	47	55	66	74	71	63	52	41	31	50
Nevada	**Rf.**	0.5	0.4	0.5	0.5	0.4	0.2	0.4	0.6	0.4	0.4	0.3	0.4	4.9
South America														
Sarmiento,	**T.**	65	63	59	51	44	38	38	42	46	53	57	61	51
Argentina	**Rf.**	0.1	0.3	0.5	0.4	0.8	0.6	0.8	0.4	0.4	0.4	0.2	0.2	5.1
Eurasia														
Astrakhan,	**T.**	19	21	32	48	64	73	77	74	63	50	37	26	49
U. S. S. R.	**Rf.**	0.5	0.3	0.4	0.5	0.7	0.7	0.5	0.5	0.5	0.4	0.4	0.5	5.9

HUMID MARINE CLIMATE (IM)

Station		*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Annual*
North America														
Sitka,	**T.**	32	34	36	41	47	51	55	56	52	46	38	35	44
Alaska	**Rf.**	7.6	6.5	5.6	5.5	4.1	3.4	4.2	7.1	10.2	12.2	9.5	9 0	84 8
Victoria,	**T.**	39	40	44	48	53	57	60	60	56	50	45	41	49
Br. Columbia	**Rf.**	4.6	3.2	2.4	1.5	1.1	0.9	0.4	0.6	1.8	2.6	5 0	5.6	29.7
Seattle,	**T.**	40	42	45	50	55	60	64	64	59	52	46	42	52
Washington	**Rf.**	4.8	3 8	3.1	2 4	1 8	1 3	0.6	0.7	1.7	2.8	4 8	5.5	33 4
South America														
Valdivia,	**T.**	60	59	57	54	51	49	46	46	49	51	53	57	53
Chile	**Rf.**	2.9	3.2	6.4	9.3	15 3	17.5	15.4	13.5	7 3	5.0	4 4	4.8	105 0
Punta Arenas,	**T.**	52	51	48	44	39	36	35	37	40	44	47	50	44
Chile	**Rf.**	1.4	1.2	1 7	1.6	1.6	1.2	1.2	1.2	1.1	0.8	1 1	1.4	15.5
Eurasia														
Valencia,	**T.**	44	44	45	48	52	57	59	59	57	52	48	46	51
Eire	**Rf.**	5 5	5 2	4.5	3.7	3.2	3.2	3.8	4.8	4.1	5.6	5 5	6.6	55.7
Aberdeen,	**T.**	38	38	40	44	48	54	57	56	53	47	42	39	46
Scotland	**Rf.**	2.2	2.1	2.4	1.9	2.3	1.7	2.8	2.7	2.2	3.0	3 0	3.2	29.5
Bergen,	**T.**	34	34	36	42	49	55	58	57	52	45	39	36	45
Norway	**Rf.**	9.0	6.6	6.2	4.3	4.7	4.1	5.7	7.8	9.2	9.3	8.5	8.9	84.3
Copenhagen,	**T.**	32	32	35	42	51	59	62	61	55	47	39	34	46
Denmark	**Rf.**	1.5	1.3	1.4	1.4	1.5	2.0	2.4	2.6	2.1	2.2	1.9	1 7	22.0
Brest,	**T.**	45	45	47	50	55	60	65	64	61	50	50	46	54
France	**Rf.**	2.6	2.4	2.2	2.1	2.4	1.5	1.3	1.9	2.5	3.4	3.1	3.7	29.1
Australasia														
Hobart,	**T.**	62	62	59	55	51	47	46	48	51	54	57	60	54
Tasmania	**Rf.**	1.8	1.5	1.7	1.9	1.8	2.2	2.1	1.9	2.1	2.2	2.5	2.0	23.7
Wellington,	**T.**	63	63	61	57	53	49	48	49	52	54	57	60	55
New Zealand	**Rf.**	3.3	3.1	3.3	3.9	4.7	4.8	5.6	4.5	4.0	4.1	3.5	3.2	48.0

HUMID CONTINENTAL CLIMATES (IC)

Station		*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Annual*
North America														
Omaha,	T.	22	26	37	51	62	72	77	74	67	54	38	26	51
Nebraska	Rf.	0.7	0.9	1.4	2.5	3.8	4.6	3.5	3.0	3.2	2.2	1.1	0.9	27.8
Chicago,	T.	25	27	36	48	58	68	74	73	66	55	41	30	50
Illinois	Rf.	1 9	2.1	2.6	2.8	3.5	3 3	3.3	3.2	3.1	2.5	2.4	2.0	32.9
Cincinnati,	T.	33	34	44	54	65	74	78	76	69	58	45	36	56
Ohio	Rf.	3.5	2.9	4.0	3.1	3.6	3.7	3.4	3.3	2.6	2.5	2.9	3.1	38.6
Washington,	T.	33	35	43	53	64	72	77	75	68	57	45	37	55
D. C.	Rf.	3 6	3 3	3 8	3.3	3.7	4.1	4.7	4.0	3.2	2.8	2.4	3.3	42 2
Boston,	T.	28	29	36	46	57	66	72	70	63	54	42	32	50
Massachusetts	Rf.	3.6	3.4	3.6	3.3	3 2	2 9	3.5	3.5	3.1	3.2	3.3	3.4	40.1
Edmonton,	T.	6	10	23	40	51	57	61	59	50	41	25	14	36
Alberta	Rf.	0 9	0 6	0 7	0 8	1 8	3.1	3.4	2 4	1.4	0.7	0.7	0.8	17.3
Montreal,	T.	13	14	26	41	55	65	70	67	59	47	33	20	42
Quebec	Rf.	3.8	3 2	3 5	2 5	3.0	3.5	3.7	3.5	3.5	3.3	3.5	3.7	40.7
Halifax,	T.	24	24	32	40	49	58	65	65	59	49	40	29	44
Nova Scotia	Rf.	6 0	4 7	5 1	4.6	3 8	3 8	3.7	4 6	4.1	5.5	5.9	5.5	57.3
Eurasia														
Milan,	T.	32	38	46	55	63	70	75	73	66	56	44	36	55
Italy	Rf.	2.4	2 3	2.7	3.4	4.1	3.3	2.8	3 2	3.5	4.7	4.3	3.0	39.8
Breslau,	T.	30	32	37	46	56	63	66	64	58	48	38	32	47
Germany	Rf.	1 3	1.0	1.6	1.5	2.4	2 4	3.4	2.8	2.0	1.5	1.5	1.5	22.9
Bucharest,	T.	26	31	41	52	62	69	73	72	64	53	40	31	51
Rumania	Rf.	1 3	1.1	1.6	1.7	2.5	3.5	2.7	2.0	1.6	1.7	1.9	1.6	23.1
Kiev,	T.	21	23	31	45	57	64	67	65	57	46	34	24	44
U. S. S. R.	Rf.	1.1	0 8	1.5	1.7	1.7	2 4	3.0	2.4	1.7	1.7	1.5	1.5	21.0
Moscow,	T.	12	15	24	38	53	62	66	63	52	40	28	17	39
U. S. S. R.	Rf.	1 1	0 9	1.2	1.5	1.9	2.0	2 8	2.9	2.2	1.4	1.6	1.5	21.0
Mukden,	T.	8	14	30	47	60	71	77	75	61	48	29	14	44
Manchuria	Rf.	0.2	0.3	0.8	1.1	2.2	3.4	6.3	6.1	3.3	1.6	1.0	0.2	26.5
Vladivostok,	T.	5	12	26	39	48	57	66	69	61	49	30	14	40
U. S. S. R.	Rf.	0.1	0 2	0.3	1.2	1.3	1.5	2.2	3.5	2.4	1.6	0.5	0.2	14.7
Nagasaki,	T.	42	43	48	58	64	71	78	80	74	64	55	46	60
Japan	Rf.	3.1	3.5	5.2	8.1	7.4	13 2	9.3	7.3	8.6	4.6	3.3	3.3	76.9

SUBPOLAR TAIGA CLIMATE (SPT)

Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
North America														
Eagle,	T.	−15	−4	7	27	45	55	59	53	42	25	2	−11	24
Alaska	Rf.	0.5	0.4	0.4	0.4	0.8	1.5	1.8	2.0	1.3	0.8	0.5	0.5	10.9
Ft. Vermillion,	T.	−14	−6	8	30	47	55	60	57	46	32	10	−4	27
Alberta	Rf.	0.6	0.3	0.5	0.7	1.0	1.9	2.1	2.0	1.4	0.7	0.5	0.4	12.3
Churchill,	T.	−20	−16	−3	22	32	43	56	53	42	27	8	−9	20
Manitoba	Rf.	0 6	1.0	1.1	1.0	1.0	2.0	1 8	2.5	3.6	1.3	1.2	0.9	17.9
Ft. George	T.	−10	−11	0	24	35	49	57	54	43	34	25	4	25
Quebec	Rf.	2.0	0.9	1 5	0 9	1.1	1 6	1 4	1.9	1.7	1.9	1.6	1.7	18 2
Eurasia														
Haparanda,	T.	12	11	18	29	40	53	59	55	46	35	23	15	33
Sweden	Rf.	1.5	1.1	1.0	1.0	1 2	1.5	1.8	2.1	2.4	2.2	2.0	1.4	19.2
Archangel,	T.	8	9	18	30	41	53	60	56	46	34	22	12	33
U. S. S. R.	Rf.	0.9	0.7	0 8	0.7	1.2	1.8	2.4	2.4	2.2	1.6	1.2	0.9	16.8
Verkhoyansk	T.	−58	−48	−24	9	36	56	60	52	36	6	−34	−51	3
U. S. S. R.	Rf.	0.2	0 1	0 1	0.2	0 3	0.9	1.0	1.0	0.5	0 4	0.3	0.1	5.0
Okhotsk,	T.	−11	−7	7	21	35	45	55	55	46	27	6	−8	22
U. S. S. R.	Rf.	0.1	0.1	0.1	0 2	0.5	1.1	0.5	1.8	2 1	0.7	0.2	0 2	7.5

POLAR TUNDRA CLIMATE (PT)

Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
North America														
Pt. Barrow,	T.	−19	−13	−14	−2	21	35	40	39	31	16	0	−15	10
Alaska	Rf.	0.3	0.2	0.2	0.3	0.3	0.3	1.1	0.8	0.5	0.8	0.4	0.4	5.6
Upernivik,	T.	−8	−9	−6	6	25	35	41	41	34	25	14	1	17
Greenland	Rf.	0.4	0.5	0.7	0.6	0.6	0.5	0.9	1.1	1.1	1.1	1.1	0.5	9.1
Angmagssalik,	T.	17	13	17	24	33	41	44	42	38	30	23	19	28
Greenland	Rf.	3 5	1.7	2.2	2.4	2.8	2.1	2 1	2.5	4 0	6 3	3 4	2 7	35 7
Eurasia														
Vardo,	T.	22	21	24	30	35	42	48	48	43	35	28	24	33
Norway	Rf.	2.7	2.6	2.1	1.6	1.4	1.5	1.8	2.0	2.4	2 5	2 5	2.6	25.7

POLAR ICECAP CLIMATE (PI)

Station		Jan.	Feb.	Mar	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
McMurdo Sound,	T.	24	16	4	−9	−10	−12	−15	−15	−12	−2	14	25	1
Antarctica	Rf.	No reliable record; probably less than 10 inches.												

FIG. 102.—Climates of the World. (See insert following this page.)

- T—HUMID TROPICAL CLIMATES
  - TR—Tropical rainy climates
    - TRe—Equatorial subtype
    - TRt—Trade wind subtype
    - TRm—Monsoon subtype
  - TS—Tropical savanna climate
  - TH—Tropical highland climate
- ST—SUBTROPICAL CLIMATES
  - STS—Low latitude steppe climate
  - STD—Low latitude desert climate
  - STH—Humid subtropical climate
  - STM—Mediterranean climate (dry subtropical)
- I—INTERMEDIATE (MIDDLE LATITUDE) CLIMATES
  - IS—Middle latitude steppe climate
  - ID—Middle latitude desert climate
  - IM—Humid marine (west coast) climate
  - IC—Humid continental climates
    - ICw—Warm (long summer) subtype
    - ICc—Cold (short summer) subtype
    - ICm—Modified continental subtype
- SP—SUBPOLAR CLIMATE
  - SPT—Taiga climate
- P—POLAR CLIMATES
  - PT—Tundra climate
  - PI—Icecap climate
- Mt.—MOUNTAIN CLIMATES

Index

F

G

H

I

J

K

L

M

N

O

P